Optimization of High Performance Concrete Mix Incorporating Bagasse Ash and Slag Aggregates using Statistical Method

Revanasiddappa Madihalli, Latha M S, J K Dattatreya

***Abstract**: In recent years, it is found that there is an exponential increase in use of natural resources for infrastructure development of the country. Concrete is one of the most widely used materials for any infrastructural development activities. In this research an effort is made to utilize slag aggregates and bagasse ash in High Performance Concrete as partial replacement materials for M-Sand and cement respectively. A statistical approach called Taguchi method is used for deciding various combinations of replacement levels of alternate materials along with various levels of water cement ratios. L16 Taguchi orthogonal Array is utilized to decide experiment conduction matrix. Statistical analysis of the results was carried out using Analysis of Variance(ANOVA) and the optimum mix proportions of the High Performance Concrete for better strength and durability characteristics is arrived. It is found that the mix proportion containing water cement ratio of 0.3 with 10% replacement of cement by Bagasse Ash and 20% replacement of M-sand by slag sand gives satisfactory compressive strength and split tensile strength results.*

***Keywords** : High performance concrete, optimization, bagasse ash, slag sand, Taguchi Method.*

I. INTRODUCTION

By-products from various industries are well utilized as partial replacement materials for producing different grades of concrete [1] so as to reduce the emission of carbon dioxide as a result of enormous production of cement and to reduce the excessive utilization of river sand or manufactured sand. Sugar cane bagasse ash is found to be a waste material exposed in large quantities to the environment. Based on the previous studies the bagasse ash has shown pozzolonic properties which is an essential requirement to use as binder in producing concrete[2]. There are many researchers worked on this pozzolonic material to use in concrete with good strength and durability properties. Sumrerng Rukzon[3] utilized the bagasse ash to produce high strength concrete by replacing the cement up to 30%. Durability properties of the concrete containing Bagasse ash were studied by Rattapon Somna et.al along with the recycled aggregates. It was found that use of Bagasse ash improved the water permeability of the high strength concrete and the chloride penetration depth was also decreased as the ground bagasse ash content increased[4]. Strength and heat evaluation properties of the concrete were investigated by kawee et.al[5] indicated that the inclusion of bagasse ash in concrete shows negative effect in enhancing the strength of concrete and the temperature of concrete containing bagasse ash has reduced by 13- 17% compared to conventional concrete.

Slag sand is a byproduct from steel industries which can be utilized either as coarse aggregates and fine aggregates. Now a days due to increased processing of the steel tonnes together slag has been produced by steel industries. Based on the various literatures the steel slag is found to be a suitable material to produce normal and high strength concretes. High performance concrete was developed by Yasmina et. al[6] by using steel slag at various percentages. Xin Yu et. al[7] conducted fire performance test and strength investigations on the concrete containing steel slag and recommended 100% replacement level for coarse aggregates and partial replacement for fine aggregates in concrete for improved fire performance and compressive strength results. Static and impact behavior of concrete containing steel slag studied by Yongchang Guo et. al[8] reported that use of 20% steel slag as fine aggregate replacement material for self-compacting concrete has resulted in satisfactory performance with respect to static and impact strengths. Manjunath et.al[9] adopted Taguchis optimization technique with L9 orthogonal array for development of high performance concrete using industrial waste including steel slag and arrived at optimum mix proportions of the concrete by statistical analysis of the results and the mathematical model developed based on the results. In the present study Taguchi method with L16 orthogonal array is selected for optimization of high performance concrete mix containing bagasse ash and slag sand as partial replacement materials for cement and M – sand.

II. EXPERIMENTAL PROGRAMME

Experimental programme represents the details of material characterization, replacement levels and experimental matrix for the specimen preparations.

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A.Materials used

Ordinary Portland cement confirming to IS 1489:1991 with specific gravity 3.15, Bagasse ash confirming to IS:1727 – 1998 with specific gravity 1.88, Coarse aggregates of sizes 20mm and 12mm down size confirming to IS: 383 – 1970 with specific gravity of 2.66 and water absorption of 0.3%, manufactured sand confirming to IS: 383 – 1970 with specific gravity of 2.7 and water absorption of 2.1%, slag sand of specific gravity 2.52 with water absorption of 0.4% and portbable water confirming to IS 456-2000 with P^H value less than 7 were used for the study.

B. Implementation of Taguchi Method

Table – I Factors and their levels

Factors	Levels			
W/C	0.3	0.33	0.36	0.39
BA/C	0.1	0.15	0.2	0.25
SA/FA	0.2	0.3	0.4	0.5

W/cm = water to cementitious ratio,
BA/cm = Bagasse Ash to cementitious ratio,
SA/FA = slag aggregates to fine aggregate ratio.

Based on the above factors and their levels L16 Taguchis orthogonal array is selected as given in Table - II.

Table – II L16 orthogonal Array

Expt No.	w/cm	BA/cm	SA/FA
1	0.3	0.1	0.2
2	0.3	0.15	0.3
3	0.3	0.2	0.4
4	0.3	0.25	0.5
5	0.33	0.1	0.3
6	0.33	0.15	0.2
7	0.33	0.2	0.5
8	0.33	0.25	0.4
9	0.36	0.1	0.4
10	0.36	0.15	0.5
11	0.36	0.2	0.2
12	0.36	0.25	0.3
13	0.39	0.1	0.5
14	0.39	0.15	0.4
15	0.39	0.2	0.3
16	0.39	0.25	0.2

C. Mix Proportioning

The mix design was performed as per IS 10262-2009. The details of the mix proportioning are given in Table V.

III. RESULTS AND DISCUSSIONS

A. Workability

Slump cone test as per IS 1199-1959 was performed to measure the workability of high performance concrete. Conplast - 450 superplasticizer was used to get the required workability and the dosage was varied to achieve a slump of 100mm to 125mm.Table III gives the results of slump cone test.

From the experimental results it is observed that the non-spherical nature of slag sand and the fibrous texture of bagasse ash particles interfere with the workability of concrete increases the super plasticizer dosage.

Low water absorption of slag sand promotes the workability, on the other hand some amount of water is absorbed by the bagasse ash.

As the water cementitious ratio decreases, the volume of fines consisting of cementitious binder increases and the workability decreases.

Table – III Factors and their levels

w/cm	BA/cm	SA/FA	Super plasticize r (%)	Water content (liters)	Slump value (mm)
0.3	0.1	0.2	1.56	158	105
0.3	0.15	0.3	1.82	158	100
0.3	0.2	0.4	2.06	158	105
0.3	0.25	0.5	2.34	158	110
0.33	0.1	0.3	1.29	158	120
0.33	0.15	0.2	1.48	158	120
0.33	0.2	0.5	1.73	158	110
0.33	0.25	0.4	2.09	158	105
0.36	0.1	0.4	1.16	158	120
0.36	0.15	0.5	1.31	158	110
0.36	0.2	0.2	1.51	158	110
0.36	0.25	0.3	1.78	158	100
0.39	0.1	0.5	0.74	158	120
0.39	0.15	0.4	0.92	158	110
0.39	0.2	0.3	1.19	158	115
0.39	0.25	0.2	1.43	158	100

B. Compressive Strength

The Table - IV gives the compressive strength test results at 7 days, 28 days and 56days age of concrete.

Table – IV Compressive Strength results

w/cm	BA/cm	SA/FA	7 days Strength	28 days Strength	56 days Strength
			MPa	*MPa*	*MPa*
0.3	0.1	0.2	59.93	82.8	85.62
0.3	0.15	0.3	47.38	78.24	82.42
0.3	0.2	0.4	44.56	68.96	71.98
0.3	0.25	0.5	42.18	58.96	62.04
0.33	0.1	0.3	50.81	70.7	73.42
0.33	0.15	0.2	43.14	67.66	70.78
0.33	0.2	0.5	42.69	59.94	63.89
0.33	0.25	0.4	37.71	53.67	57.49
0.36	0.1	0.4	40.15	65.45	68.49
0.36	0.15	0.5	38.67	59.84	63.93
0.36	0.2	0.2	36.19	52.18	56.20
0.36	0.25	0.3	34.82	47.81	51.04
0.39	0.1	0.5	37.6	57.04	59.80
0.39	0.15	0.4	34.82	51.53	55.27
0.39	0.2	0.3	27.53	43.04	45.24
0.39	0.25	0.2	25.06	39.77	42.18

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Table - V Concrete mix Proportioning

Expt No.	Water	Cement (OPC)	Bagasse Ash	Slag aggregates	M Sand	Coarse Aggregates
	(liters)	*(Kg/m³)*	*(Kg/m³)*	*(Kg/m³)*	*(Kg/m³)*	*(Kg/m³)*
1	153	458	51	117	469	1130
2	152	429	76	175	407	1122
3	151	403	101	230	344	1118
4	150	373	124	287	287	1107
5	152	416	46	185	432	1138
6	152	391	69	123	492	1134
7	150	365	91	304	304	1123
8	150	341	114	243	364	1119
9	152	381	42	251	376	1158
10	151	357	63	312	312	1150
11	151	337	84	125	499	1151
12	150	314	105	186	434	1144
13	152	350	39	328	328	1156
14	151	330	58	262	392	1153
15	151	310	77	196	457	1151
16	151	290	97	130	521	1148

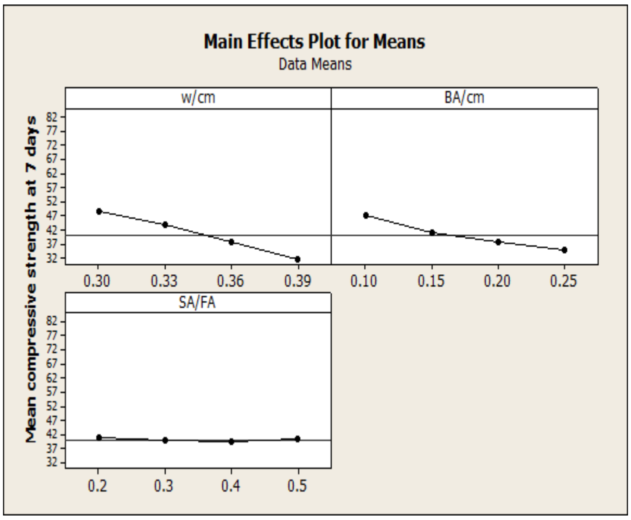

Figure 1 Main effect plot of means for 7 days cube compressive strength

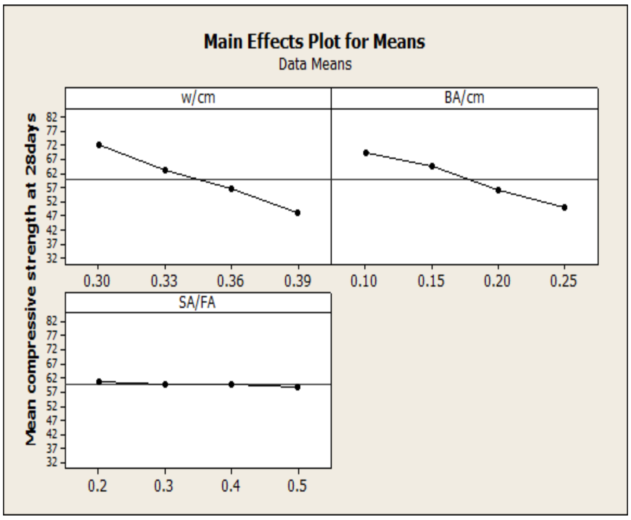

Figure 3 Main effect plot of means for 28 days cube compressive strength

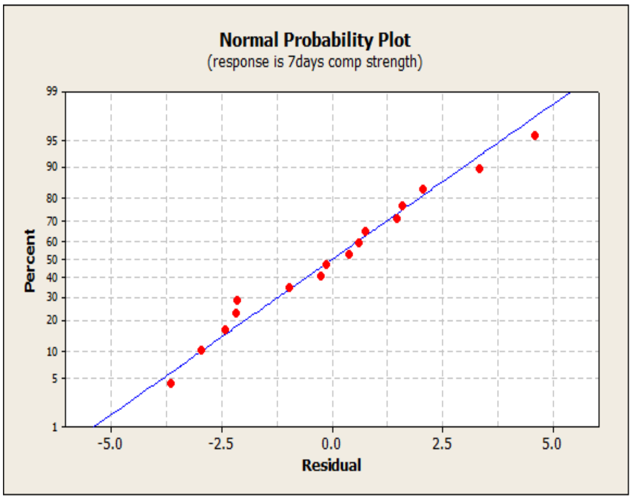

Figure 2 Normal probability plot for 7 days cube compressive strength

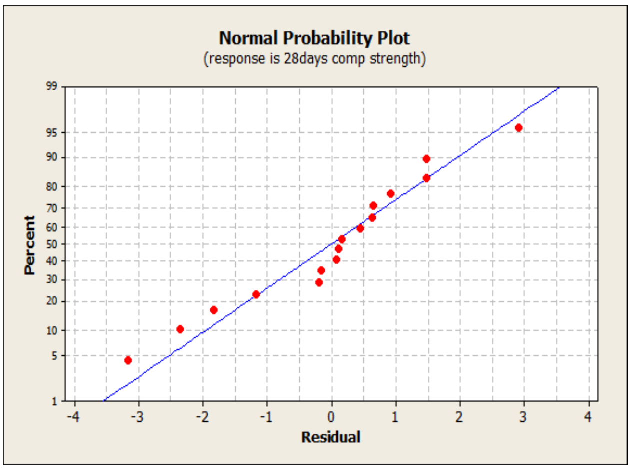

Figure 4 Normal probability plot for 28 days cube compressive strength

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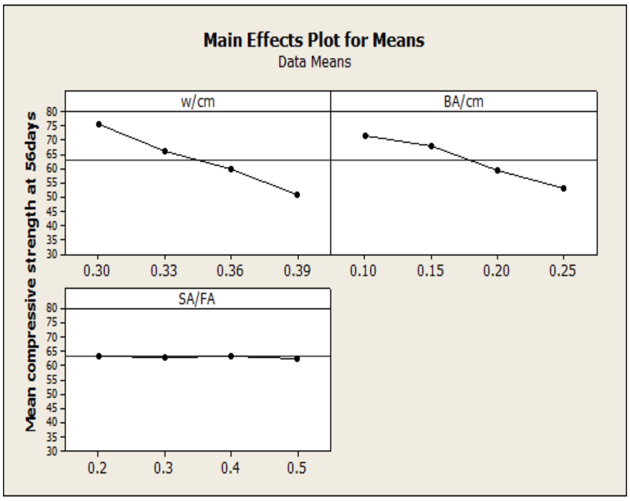

Figure 5 Main effect plot of means for 56 days cube compressive strength

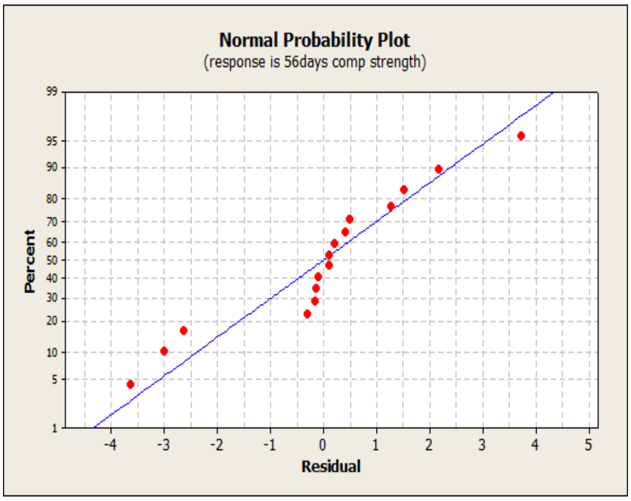

Figure 6 Normal probability plot for 56 days cube compressive strength

Table - VI Predicted Optimum levels of the Parameters for Compressive Strength

SI No.	Performance Parameters	w/cm	BA/cm	SA/FA
1	7 days compressive strength	0.30	0.10	0.20
2	28 days compressive strength	0.30	0.10	0.20
3	56 days compressive strength	0.30	0.10	0.10

Table - VII Analysis of Variance

SI No.	Performance Parameters	7 days compressive strength	28 days compressive strength	56 days compressive strength
1	Contribution of w/cm	62.85%	59.15%	59.89%
2	Contribution of BA/cm	30.74%	39.60%	38.69%
3	Contribution of SA/FA	0.59%	0.26%	0.16%

Referring to the main effect plots for compressive strengths at various ages, maximum strength is obtained for w/cm of 0.30, and the strength has decreased for further increase in w/cm ratio which is the consequence of Abram's law and is due to increase in porosity with increase in w/cm.

Table - VIII Regression Analysis

Performance Parameters	Regression Equation
7 days compressive strength	7days comp strength = 122 - 193 w/cm - 79.6 BA/cm - 3.21 SA/FA
28 days compressive strength	28days comp strength = 176 - 266 w/cm - 130 BA/cm - 5.02 SA/FA
56 days compressive strength	56days comp strength = 180 - 271 w/cm - 129 BA/cm - 3.56 SA/FA

Optimum Bagasse ash content for higher compressive Strength is found to be 10% after which there is a drastic decrease in the strength. This may be due to the complete reaction of free lime in the concrete with the reactive silica of bagasse ash up to 10% replacement above which the relative cement content reduces the free lime content decreases as the percentage of bagasse ash is increased. And Referring to nature of main effect plots for SA/FA ratio it is clear that the replacement level of slag sand does not significantly affect the strength of the concrete. Therefore, the type of the fine aggregate does not matter.

From the table VII of analysis of variance, percentage contribution of w/cm on compressive strengths at various ages is more compared to the contribution of other factors, which indicates that the factor has high level of importance when compared to other factors.

C. Split Tensile Strength

The Table - IX gives the split tensile strength test results at 7 days, 28 days and 56days age of concrete.

Table - IX split tensile strength results

w/cm	BA/cm	SA/FA	7 days split tensile Strength	28 days split tensile Strength	56 days split tensile Strength
			MPa	*MPa*	*MPa*
0.3	0.1	0.2	3.49	4.56	4.78
0.3	0.15	0.3	2.90	4.23	4.52
0.3	0.2	0.4	3.06	3.82	4.05
0.3	0.25	0.5	2.69	3.31	3.43
0.33	0.1	0.3	3.30	3.92	4.04
0.33	0.15	0.2	2.73	3.84	3.90
0.33	0.2	0.5	3.48	3.91	4.02
0.33	0.25	0.4	2.52	3.24	3.34
0.36	0.1	0.4	2.69	3.64	3.76
0.36	0.15	0.5	2.48	4.19	4.27
0.36	0.2	0.2	2.54	3.26	3.33
0.36	0.25	0.3	2.42	2.99	3.08
0.39	0.1	0.5	2.85	4.40	4.45
0.39	0.15	0.4	2.49	3.17	3.28
0.39	0.2	0.3	2.51	2.83	2.94
0.39	0.25	0.2	1.97	2.45	2.58

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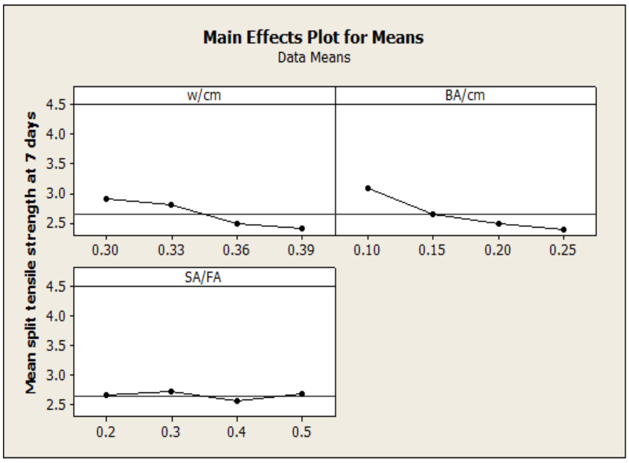

Figure 7 Main effect plot of means for 7 days split tensile strength

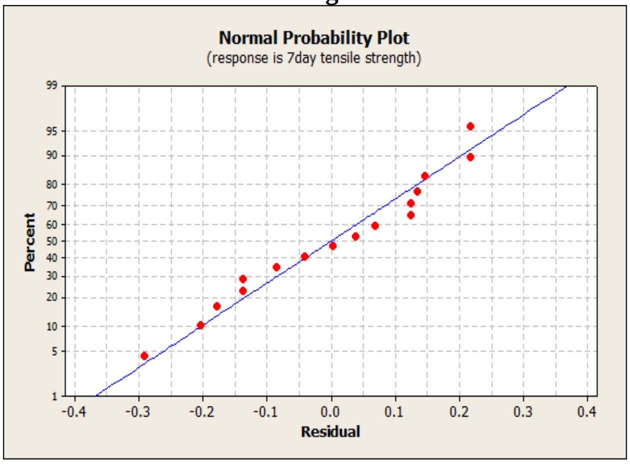

Figure 8 Normal probability plot for 7 days split tensile strength

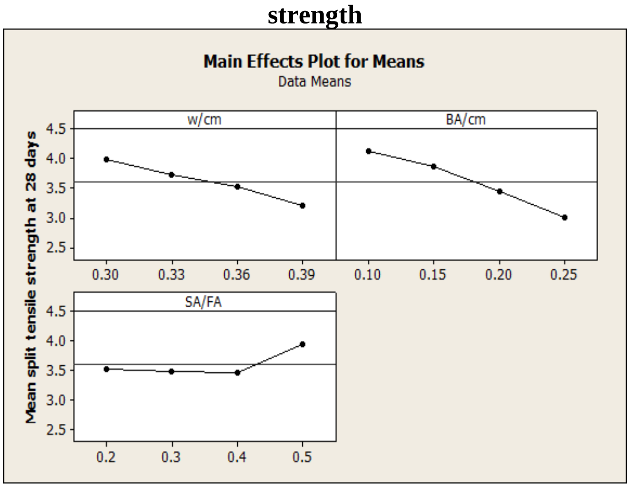

Figure 9 Main effect plot of means for 28 days split tensile strength

Table – X Predicted Optimum levels of the Parameters for Split Tensile Strength

SI No.	Performance Parameters	w/cm	BA/cm	SA/FA
1	7 days Split Tensile Strength	0.30	0.10	0.50
2	28 days Split Tensile Strength	0.30	0.10	0.50
3	56 days Split Tensile Strength	0.30	0.10	0.50

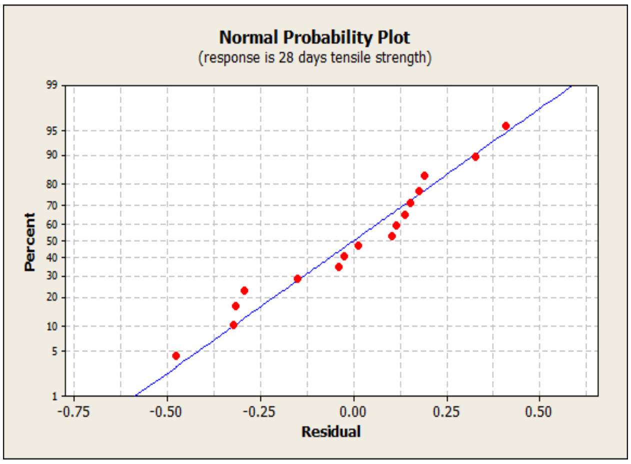

Figure 10 Normal probability plot for 28 days split tensile strength

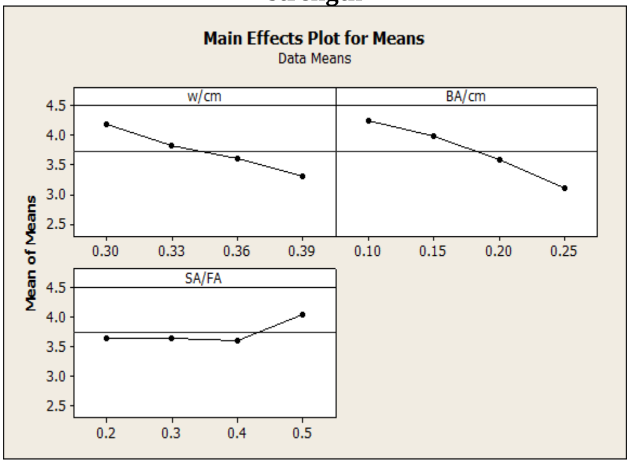

Figure 11 Main effect plot of means for 56 days split tensile strength

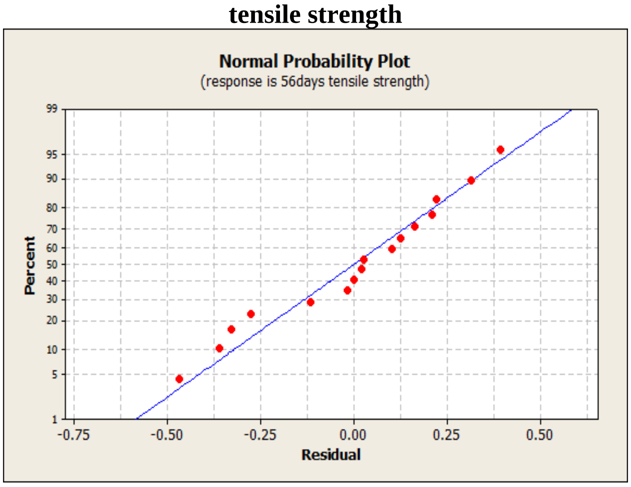

Figure 12 Normal probability plot for 56 days split tensile strength

Table - XI Analysis of Variance

SI No .	Performance Parameters	7 days Split Tensile Strength	28 days Split Tensile Strength	56 days Split Tensile Strength
1	Contribution of w/cm	33.70%	23.41%	28.43%
2	Contribution of BA/cm	55.92%	54.01%	51.91%
3	Contribution of SA/FA	2.87%	11.69%	8.70%

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Table - XII Regression Analysis

Performance Parameters ↓	Regression Equation
7 days Split Tensile Strength	7day split tensile strength = 5.54 - 5.99 w/cm - 4.53 BA/cm - 0.097 SA/FA
28 days Split Tensile Strength	28 days split tensile strength = 7.39 - 8.37 w/cm - 7.60 BA/cm + 1.25 SA/FA
56 days Split Tensile Strength	56days split tensile strength = 7.98 - 9.54 w/cm - 7.72 BA/cm + 1.15 SA/FA

From the main effect plots it is seen that as the w/cm ratio is increased, mean split tensile strength decreased. This decrease may be due to the increase in porosity of cement paste especially at the interface. The cement replacement of 10% by bagasse ash is found to be optimum replacement level for 7 days, 28 days, and 56 days split tensile strengths. It is also observed that as the percentage of slag sand increases, the split tensile strength of the concrete also increases. The increase in the split tensile strength may be due to the fibrous nature and non-spherical surface of slag sand particles which increases the interfacial bond. There is considerable percentage contribution of BA/cm on the split tensile strength at all the ages of concrete which indicates that the factor has high level of importance on the split tensile strength of the concrete.

IV. CONCLUSIONS

- Increase in Bagasse ash found to demand increased superplasticizer content to maintain the required workability whereas increase in addition of slag sand proven to enhance the flow ability of HPC.
- Bagasse ash at 10% replacement of cement can be considered as optimum replacement level to achieve good mechanical properties of concrete.
- Similar trends of compressive strength and split tensile strength results have been obtained for various replacement levels of fine aggregates by slag sand. Hence slag sand can be utilized up to 50% replacement levels to produce HPC.
- The mathematical formulations arrived for different mechanical properties can be utilized to produce the specified grade of HPC within the range of investigation.

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Dr. J K Dattatreya holds Ph.D. degree, Master of Engineering and Bachelor of Engineering degree from University Visvesvaraya College of Engineering, Bengaluru. He worked as Grade IV scientist at CSIR-Structural Engineering Research Centre, Chennai for 21 years and as Research Professor at Siddaganga Institute of Technology, Tumkur for 7 years. He published more than 30 research papers in International and National journals, guided 2 Ph.D students and handled a number of government sponsored research projects.

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