Application of Response Surface Methodology for Optimization of Alkali Activated Slag Concrete

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Abstract— **Alkali-activated aluminosilicates, commonly known as "geopolymers", are being increasingly studied as a potential replacement for Portland cement. These binders use an alkaline activator, typically alkali silicates, alkali hydroxides or a combination of both along with a silica-and-alumina rich material, such as fly ash or slag, to form a final product with properties comparable to or better than those of ordinary Portland cement. The research focuses on the strength properties of alkali activated slag (AAS) and fly ash based geopolymer concrete called alkali activated slag concrete. It is concluded that AAS and fly ash based alkali activated slag concretes can exhibit comparable strength to OPC and slag-blended OPC concretes. The cost and ecological analysis of alkali activated slag concretes, if designed rationally by careful selection of ingredients and their proportions of Alkali Activator Solution (AAS), can have lower contents of ecologically important factors such as Embodied Energy (EE) and Embodied Carbon dioxide Emission (ECOE) and thus lower carbon footprint, compared to conventional concretes (CCs).**

The strength properties of alkali activated slag concretes are compared by using Response surface methodology (Minitab software).The basic properties of alkali activated slag concretes, namely compressive strength, flexural strength and split tensile strength which in turn depends on the process of parameters, such as amount of fly ash content ,dosage of sodium oxide and activator modulus. The relationships of these input parameters with the properties of the Geopolymer concrete are complex in nature. Design of experiments (DOE) with response surface methodology was used to develop the said input–output relationships.

Index Terms— Sodium hydroxide, Sodium silicate, Fly ash, GGBFS, Steel slag,

I. INTRODUCTION

I-I General

Concrete is the most widely used material in the construction industry. Concrete is made up of various constituents like cement, aggregates, water, admixtures etc. Concrete is a composite material composed of granular materials like coarse aggregates embedded in a matrix and bound together with cement or binder which fills the space between the particles and glues them together Mindless et al. (2003) It is widely known that the production of Ordinary Portland Cement (OPC) consumes considerable energy and at the same time, production of one ton of OPC also releases one ton of CO_2 into the atmosphere. The necessity for a low CO_2 cement replacement for OPC is becoming increasingly important. Considering the crucial importance of infrastructure development for the Indian economy, Alkali activated slag concretes have attracted much attention as a potential replacement of OPC due to the fact that the production of alkali activated slag concretes cement creates substantially less CO_2 emissions. Alkali activated slag concretes also have the potential to be made using industrial waste materials, such as Ground Granulated Blast Furnace Slag (GGBFS) further enhancing the environmental credentials. Huge volumes of fly ash are generated around the world. Most of the fly ash is not effectively used, and a large proportion of it is disposed off in landfills. As the need for power increases, the volume of fly ash produced will increase. Alkali activated ground blast furnace slag blended with fly ash will provide a potential solution as it can utilize this waste product preventing it from going into landfill or tailings dams.

Steel or Linz-Donawitz(LD) slag, produced during conversion of raw iron into steel using the Linz-Donawitz process, is one suitable alternative for natural aggregates. It is also referred to as Blast Oxygen Furnace Slag (BOF) slag, is a co-product of the iron and steel making process. But in present alkali activated slag fly ash concrete, we used only normal aggregates.

I-II Response surface methodology: Preview

It is interesting to note that instead of conducting all the experiments some researchers were tried to establish the analytical relationships between the parameters by conducting only some experiments, which will affect the strength properties of alkali activated slag concrete.

The general approach to concrete mixture proportioning can be described by the following steps:

- Identifying a starting set of mixture proportions.
- Performing one or more trial batches, starting with the mixture identified in above step above, and adjusting the proportions in subsequent trial batches until all criteria are satisfied.

Employing statistical methods in the trial batch process does not change the overall approach, but it changes the trial batch process. Rather than selecting one starting point, a set of trial batches covering a chosen range of proportions for each component is defined according to established statistical procedures. Trial batches are then carried out, test specimens are fabricated and tested, and results are analyzed using standard statistical methods. In these models, each response (resultant concrete property) such as compressive strength, flexural strength and split tensile strength are expressed as an algebraic function of factors (individual component proportions) such as fly ash content, activator modulus and sodium oxide dosage.

Moreover, the statistical modeling using Design of Experiments (DOE) was proven to be an effective tool for studying the complex relationships of number of independent variables on response factor of a particular process. MINITAB software was used for this purpose.

I-III Need for the study

- The global demand of cement for construction of infrastructures is continuously increasing in order to maintain the ongoing growth and accommodate the needs of the increasing population. Therefore, development of alternative binders utilising industrial by-products is necessary to reduce the carbon footprint of the construction industry.
- As a relatively new material, it is necessary to study the various properties of AASC as compared to the traditional OPC concrete in order to determine its suitability for structural applications.
- The ongoing research on fly ash-based alkali activated slag concrete studied several short-term and long-term properties.
- The cost of local sand is only 50 to 70% of imported freshwater sand. Mining and application of sea sand has compensated for the shortage of freshwater sand.

I-IV Objectives of the study

- To obtain the optimum mix proportion for the alkali activated slag concrete mix design so that the maximum strength shall be achieved and with ease of workability.
- The main objective is to decrease the number of trail mixes for obtaining the optimum mixture.
- Evaluation of mechanical properties of alkali activated slag concrete mixes for pavements using normal aggregates.
- Estimating cost of production for alkali activated slag concrete with normal aggregates for concrete pavements.

II. DEVELOPMENT OF DESIGN MATRIX, MATERIAL PROPERTIES AND MIX DESIGN

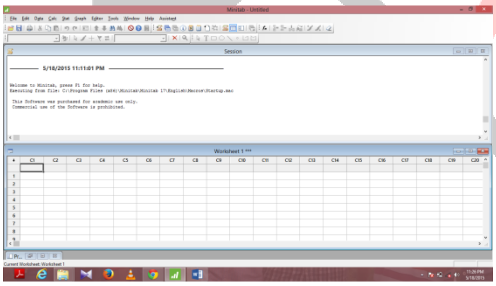
II.I introduction: This chapter also provides a detailed description of the various steps involved in the mix design process for OPCC, AASC and AASFC mixes. The materials used, preparation of specimens and evaluation of hardened concrete in terms of compressive strength, split tensile strength and flexural strength.

II-II Identification of Important Process Parameters and Their Levels*:* The alkali activated slag concrete consists of mainly three ingredients, namely fly ash, Sodium oxide dosage and activator modulus like Fly ash, Sodium oxide dosage, Activator modulus (Ms),

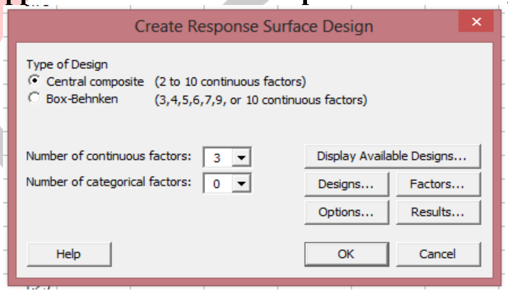
II-III Ingredient Materials: Cement Ground Granulated Blast-Furnace Slag (GGBFS) Fly Ash (FA), Fine Aggregates, Coarse Aggregates, Water, Alkaline Activators

II-IV Appendices*:* The experimental design shown in the screen shots as following

Appendix: 1. layout of the MINITAB 17



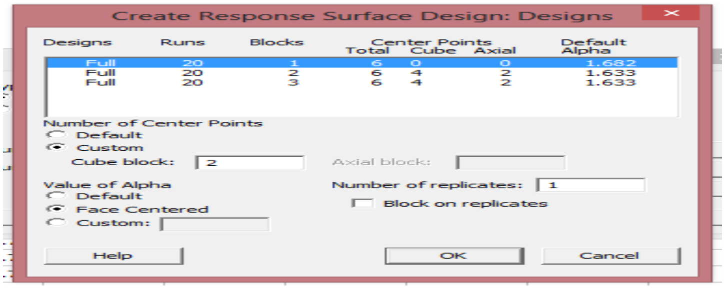
Appendix 2. Creation of response surface design



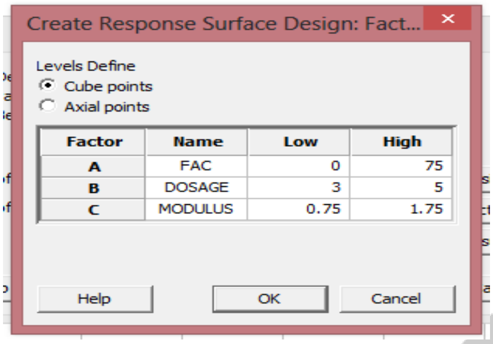
Appendix 2: Start > DOE > Response surface design > Create a Response surface design

Appendix 3. Creation of response surface design

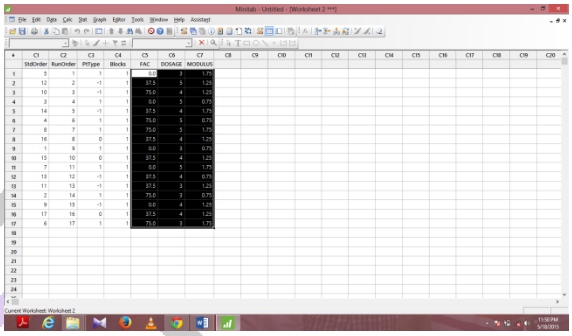
- Select factors on Response surface design - Select cube points - Enter the factors as FAC 0 – 75, DOSAGE 3 – 5, MODULUS 0.75 – 1.75 - Click OK



Appendix 4. Entering the input parameter ranges



Appendix 5. The possible combinations among FAC, DOSAGE AND MODULUS



II-V Concrete mix design details:

The total binder content is restricted to 425 kg/m^3, with water/binder ratio of 0.4 and coarse aggregate to fine aggregate ratio of 0.64:0.36. The mixes are designed to achieve a slump value of 25-50mm.The AASC mixes are proportioned to contain same binder content (425 kg/m^3) and water/binder ratio (0.4) as that of OPCC mix. The AASFC were prepared by varying the fly ash content 0 to 75%, activator modulus 0.75 to 1.75 and sodium oxide 3 to 5%. The total water content in the activator solution for AASC mixes constituted the sum of water readily available in liquid sodium silicate solution plus the extra water added, to arrive at the required water/binder ratio.

II-VI Mixing, Placing, Compacting and Curing of Concrete Mixes:

The mixing, placing and compaction of AASC and AASFC were done in a similar way as that of conventional concrete. The wet mix are thoroughly compacted on a vibrator and are then allowed to stand in humid and cool place with relative humidity 80-90% and at a temperature of 27±2°C for about 24 hours. After 24 hours, then the specimens were remolded. After remolding the OPCC specimens were cured in water tank at room temperature of (27±3°C) while the AASC specimen were subjected to curing at relative humidity of 80-90% and room temperature of (27±3°C).

LITERATURE REVIEW

Response surface methodology:

Response surface methodology (RSM) consists of a set of statistical methods that can be used to develop improve, or optimize products (Myers, R.H. and D.C. Montgomery). RSM typically is used in situations where several factors (the proportions of individual component materials such as fly ash content, activator modulus and sodium oxide dosage) influence one or more performance characteristics, or responses (strength properties of the concrete such as compressive, flexural and split tensile strengths). RSM may be used to optimize one or more responses (e.g., maximize flexural strength, minimize split tensile strength), or to meet a given set of specifications (e.g., a minimum split tensile strength specification or an allowable range of activator modulus values). There are three general steps that comprise RSM: experiment design, modeling, and optimization.

Adam. A.A., Molyneaux, T.C.K., Patnaikuni and Law, D.W. (2010), Alizadeh, R., Chini, M., Ghods, P., Hoseini, M., Montazer, S., and Shekarchi, M. (2003), Surekha.B, Hanumanta Rao.D, Krishna Mohana Rao.G, Pandu R Vundavilli., and Parappagoudar.M,B. (2013), Bakhrev, T. (2005), Bernal, S. A., Provis, J. L., Rose, V, and Gutierrez, R.M. (2011), Bkharev, T., Sanjayan, J.G., and Cheng, Y.B. (1999), Cengiz, D., Atis,C.B., Zlem, O., Elik, C., and Okan, K. (2009), Chi, M., and Huang, R. (2012), Davidovots, J.J.,. (1994), M.B.Pappagoudar., D.K. Pratihar., and G.L. Datta. (2011).

III. RESULTS AND DISCUSSIONS

III-I Workability and Unit Weight:

The slump test was performed according to the procedure suggested in IS 1199:1959. The OPCC, AASC and AASFC mixes attained the target slump values for which they were designed. During the preliminary investigation it was observed that the slump increases with the inclusion of higher FA content in AASC mixes. It was noticed that the workability increases drastically after inclusion of more than 50% FA in the AASFC mix.

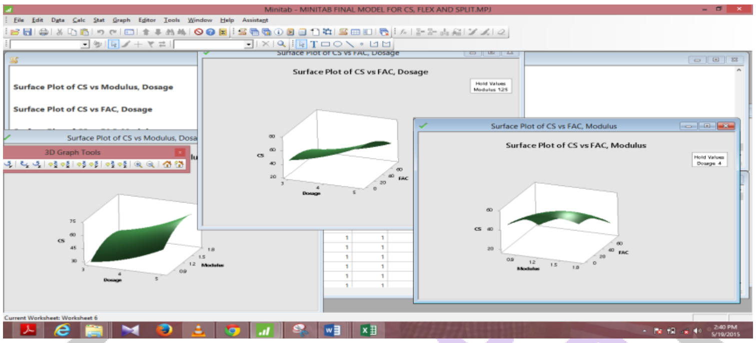
III-II Compressive Strength of Concrete Mixes:

Compressive strength tests were conducted as per IS 516-1959 at 28 days of curing .The 28-days compressive strength of AASC is low, AASFC mixes with fly ash 37.5% are medium and AASFC mixes with fly ash 75% are high. The AASC samples with normal aggregates exhibit higher compressive strength as compared to OPCC samples. It is a well established fact that the bond between the aggregate and the paste significantly affect the mechanical properties of concrete. If there exists a stronger bond between the paste and coating layer than the bond between the coating and the aggregate surface, it may lead to the development of weak coating-aggregate interface thus leading to the reduction in mechanical properties of the concrete.

III-III Statistical Analysis for compressive strength:

The laboratory compressive strength values of alkali activated slag concrete has been used to develop non-linear regression models. Further, the analysis of the models is performed through ANOVA test and surface plots for the response – compressive strength.

Appendix. 1: surface plots for the response compressive strength



Start > DOE > Response surface > Surface plots, Select CS – compressive strength and generate plots on separate graphs.

III-IV Response – compressive strength:

Equation (3) shows the non-linear model expressed as a function of input process parameters (in coded form), that represents the compressive strength of the alkali activated slag concrete system.

$$CS = 15.6 - 25.1 \times DOS + 84.3 \times MOD + 0.221 \times FAC + 4.76 \times (DOS)^2 - 33.4 \times (MOD)^2 - 0.00415 \times (FAC)^2 + 2.50 \times DOS \times MOD - 0.0553 \times DOS \times FAC - 0.0173 \times MOD \times FAC$$

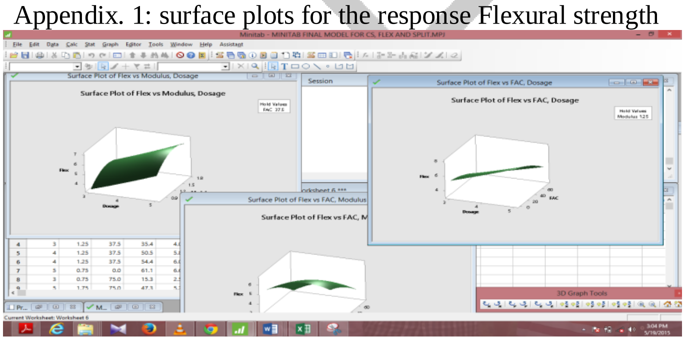
III-V Static Flexural Strength of Concrete Mixes:

The static flexural strengths for all concrete specimens were determined according to IS 516:1959. Table shows the 28 days results of flexural strength of AASC mixes with 0% fly ash, AASFC mixes with 37.5% fly ash and 75% fly ash by varying the activator modulus and sodium oxide dosage. From the results in table AASC and AASFC mixes with natural aggregates display higher flexural strength than OPCC concrete at all ages, which may due to the presence of highly dense interfacial transition zone between the paste and the aggregates and development of a distinct microstructure as compared to cement concrete.

III-V-I Statistical Analysis for flexural strength:

The laboratory flexural strength values of alkali activated slag concrete has been used to develop non-linear regression models. Further, the analysis of the models is performed through ANOVA test and surface plots for the response – Flexural strength.

Appendix. 1: surface plots for the response Flexural strength



Enter the flexural strength values obtained from laboratory for each combination in the MINITAB 17 and analyzed.

Start > DOE > Response surface > Surface plots, Select Fex – Flexural strength and generate plots on separate graphs.

III-V-II Response – Flexural strength:

The mathematical relationship given in Eqn. (5) shows the non-linear relationship of flexural strength of alkali activated slag concrete with the input process parameters in coded form.

$$\text{Flex} = -3.87 + 0.93\ \text{DOS} + 8.53\ \text{MOD} + 0.0051\ \text{FAC} + 0.034 \times (\text{DOS})^2 - 3.22 \times (\text{MOD})^2 - 0.000221\ (\text{FAC})^2 + 0.120 \times \text{DOS} \times \text{MOD} - 0.00460 \times \text{DOS} \times \text{FAC} - 0.00147 \times \text{MOD} \times \text{FAC}$$

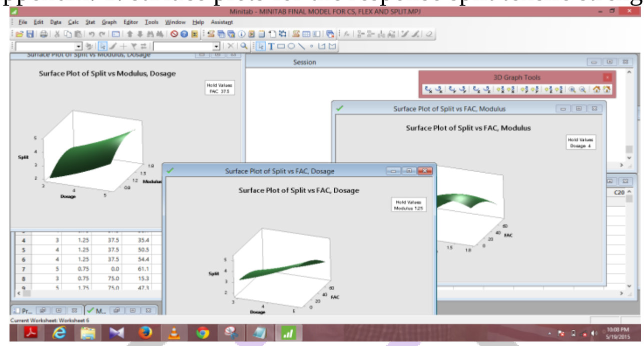
III-VI Split tensile strength of concrete mixes:

The spilt tensile strength test was conducted as per IS 5816:1999. Table shows the 28 day split tensile strength values for AASC with 0% fly ash, AASFC mixes with 37.5% fly ash and 75% fly ash by varying the activator modulus and sodium oxide dosage. The split tensile strength of AASC and AASFC mixes with normal aggregates is higher than OPCC.

III-VI-I Statistical Analysis for split tensile strength:

The laboratory split tensile strength values of alkali activated slag concrete has been used to develop non-linear regression models. Further, the analysis of the models is performed through ANOVA test and surface plots for the response – split tensile strength.

Appendix. 1: surface plots for the response split tensile strength



Enter the split tensile strength values obtained from laboratory for each combination in the MINITAB 17 and analyzed.

Start > DOE > Response surface > Surface plots, Select Split – split tensile strength and generate plots on separate graphs.

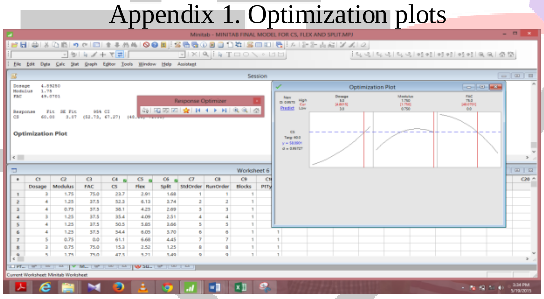
III-VI-II Response – Split tensile strength:

The mathematical relationship given in Eqn. (6) shows the non-linear relationship of split tensile strength of alkali activated slag concrete with the input process parameters in coded form.

$$\text{Split} = -1.51 - 0.08\ \text{DOS} + 5.33\ \text{MOD} + 0.0055\ \text{FAC} + 0.126 \times (\text{DOS})^2 - 2.137 \times (\text{MOD})^2 - 0.000234\ (\text{FAC})^2 + 0.118 \times \text{DOS} \times \text{MOD} - 0.00370 \times \text{DOS} \times \text{FAC} - 0.00447 \times \text{MOD} \times \text{FAC}$$

III-VII Optimization plots for all the responses:

Appendix 1. Optimization plots



Start >DOE > Response surface > Response optimizer.

Select goal as target/maximum/minimum for any response and give the corresponding value.

III-VIII Validation of Response surface methodology:

The validation of response surface methodology checked by Considering some random input parameters fly ash content, activator modulus and sodium oxide dosage. The alkali activated slag concrete samples were prepared by following codel provisions mentioned above. The mechanical properties compressive strength , flexural strength and split tensile strength are compared with the results in response surface methodology.

TABLES:

Table 1: The Process parameters and their chosen levels

Parameter	**Levels**		
	Low(-1)	**Medium(0)**	**High(+)**
Fly ash content (%)	0	37.5	75
Sodium oxide dosage (%)	4	5	6
Activator modulus	0.75	1.25	1.75

Table 2: Properties of OPC used in this study

SI. NO	Test	Result(OPC)	Limits as per IS 8112-2013
1	Specific Gravity	3.14	-
2	Standard Consistency,%	30	-
3	Fineness of Cement(m^2/kg) (Blaine's air permeability)	330	>225
4	Setting time - Initial(minutes)	65	>30
	- Final (minutes)	375	<600
5	Compressive strength (Mpa) 3 Days	29	23
	7 Days	40	33
	28 Days	57	43-58

Table 3: Chemical and Physical Properties of Fly ash (Class F)

Chemical properties	Composition (%)	Requirements as per IS 3812(Part 2)- 2003
SiO_2	59.75	35% min
Al_2O_3	26.06	SiO_2+ Al_2O_3+ Fe_2O_3 Combined 70% max
Fe_2O_3	6.73	
CaO	3.05	5% max
Na_2O	0.93	Total alkalies 5% max
K_2O	1.54	
SO_3	0.65	2.75% max
Loss of Ignition	1.26	12% max
Fineness (m_2/kg)	350	320
Specific Gravity	2.2	-

Table 4: Properties of Sodium Silicate solution

Constituent	Percentage
Na_2O % (by weight)	14.7
SiO_2 % (by weight)	32.8
Water % (by weight)	52.5
% of solids (by weight)	47.5
Ms (SiO_2/Na_2O)	2.23
Specific Gravity	1.57

Table 5: Properties of Sodium Hydroxide (97% purity)

Molecular formula	NaOH
Molar mass	39.9971 g/mol
Appearance	White solid
Specific Gravity	2.1
Solubility in water	114 g/100ml (25^{0}C)

Table 6: Mix proportions of concrete mixes

MIX ID	BINDER		NaOH	Na_2SiO_3	Fine aggregate	Coarse aggregate	Water
	GGBFS	Fly ash					
OPCC	425	-	-	-	660	1196	169
02:15.8	425	0	3.5	68.02	624	1200	134.3
01:15.8	425	0	10.9	29.15	632	1215	154.7
01:25.3	425	0	9.6	64.78	621	1193	136
01:15.8	425	0	18.17	48.59	620	1191	144.7
02:15.8	425	0	5.84	113.37	606	1165	110.5
3:1.25:37.5	266	159	7.2	48.6	612	1177	144.4
4:1.75:37.5	266	159	4.67	90.7	600	1152	122.4
4:1.25:37.5	266	159	9.6	54.78	605	1162	136
4:1.25:37.5*	266	159	9.6	54.78	605	1162	136
4:1.25:37.5*	266	159	9.6	54.78	605	1162	136
4:0.75:37.5	266	159	14.5	38.9	610	1173	149.5
5:1.25:37.5	266	159	12	80.9	598	1148	127.5
02:15.8	106	319	3.5	68	592	1140	134
01:15.8	106	319	10.9	29.15	600	1154	154
01:25.3	106	319	9.6	64.78	589	1131	136
02:15.8	106	319	5.84	113.36	574	1104	110.5
01:15.8	106	319	18.17	48.59	588	1130	144.5

Note: OPCC - represents Portland cement based control mix;

Table 7: 28 days results of compressive strength

Sodium oxide dosage	Activator modulus(Ms)	Fly ash content	Compressive strength (28 days)
3	1.75	0	42.5
3	0.75	0	33.1
4	1.25	0	59.5
5	0.75	0	61.1
5	1.75	0	74.7
3	1.25	37.5	35.4
4	1.75	37.5	45.7
4	1.25	37.5	52.3
4	1.25	37.5	50.5
4	1.25	37.5	54.4

4	0.75	37.5	38.1
5	1.25	37.5	71.9
3	1.75	75	23.7
3	0.75	75	15.3
4	1.25	75	27.8
5	1.75	75	47.3
5	0.75	75	31.9

Table 8: Results of the significance test for the non-linear model of compressive strength

Term	Coeff	SE	T	P
Constant	50.39	1.79	28.16	0
DOS	14.03	1.32	10.61	0
MOD	5.11	1.32	3.86	0.006
FAC	-12.49	1.32	-9.45	0
$(DOS)^2$	4.76	2.55	1.86	0.105
$(MOD)^2$	-8.34	2.55	-3.26	0.014
$(FAC)^2$	-5.84	2.55	-2.29	0.056
DOS x MOD	1.25	1.48	0.85	0.426
DOS x FAC	-2.08	1.48	-1.4	0.203
MOD x FAC	-0.33	1.48	-0.22	0.832

Table 8: Results of ANOVA for the response – compressive strength

Source	DF	Adj SS	Adj MS	F	P
Regression	9	4277.89	475.32	27.18	0
Linear	3	3789.53	1263.18	72.24	0
Square	3	440.57	146.86	8.4	0.01
Interaction	3	47.79	15.93	0.91	0.483
Residual error	7	122.41	17.49		
Lack of fit	5	114.79	22.96	6.03	0.148
Pure error	2	7.62	3.81		
Total	16	4400.3			

Table 9: 28 day results of flexural strength

Sodium oxide dosage	Activator modulus(Ms)	Fly ash content	Flexural strength 28days
3	1.75	0	5.06
3	0.75	0	3.93
4	1.25	0	6.93
5	0.75	0	6.68
5	1.75	0	7.42
3	1.25	37.5	4.09
4	1.25	37.5	6.13
4	1.25	37.5	5.85
4	1.25	37.5	6.05

4	0.75	37.5	4.25
5	1.25	37.5	7.06
3	1.75	75	2.91
3	0.75	75	2.52
4	1.25	75	3.48
5	1.75	75	5.22
5	0.75	75	3.95

Table 10: 28 days results of split tensile strength

Sodium oxide dosage	Activator modulus(Ms)	Fly ash content	Split tensile strength 28 days
3	1.75	0	2.87
3	0.75	0	2.32
4	1.25	0	4.42
5	0.75	0	4.45
5	1.75	0	4.78
3	1.25	37.5	2.51
4	1.75	37.5	3.38
4	1.25	37.5	3.66
4	1.25	37.5	3.7
4	1.25	37.5	3.74
4	0.75	37.5	2.69
5	1.25	37.5	4.88
3	1.75	75	1.68
3	0.75	75	1.25
4	1.25	75	2.06
5	1.75	75	3.49
5	0.75	75	2.37

Table 11: Mix design for random combinations

Mix ID	BINDER		NaOH	Na_2SiO_3	Water	Fine aggregate	Coarse aggregate
	GGBFS	Fly ash					
4.5:1.25:0	425	-	10.86	72.8	131	617	1185
3.5:1.75:50	212.5	212.5	4.08	79.36	128.37	598	1150
4.0:1.0:50	212.5	212.5	12.07	51.83	142.8	602.4	1157
4.251.36:41	250.75	174.25	9.05	74.89	130.716	600	1153
3.9:0.95:23	327.25	97.75	12.25	48	144.8	615	1182

Table 12: Comparison of compressive strength values

Mix ID	Experimental Compressive strength (MPa)	Laboratory Compressive strength (Mpa)	Difference	%age diffrence	Average %age diffrence
4.5:1.25:0	66	62	4	6.06	
3.5:1.75:50	37	33	4	10.8	
4.0:1.0:50	41.5	45	-3.5	-8.43	1.688
4.251.36:41	54	49	5	9.25	
3.9:0.95:23	47.6	52	-4.4	-9.24	

Table 13: Comparison of split tenile strength values

Mix ID	Experimental split tensile strength (MPa)	Laboratory Split tensile strength (MPa)	Difference	%age diffrence	Average %age diffrence
4.5:1.25:0	4.664	4.2	0.464	10.08	
3.5:1.75:50	2.676	2.8	-0.124	-4.633	
4.0:1.0:50	3.007	3.3	-0.293	-9.74	-3.94
4.251.36:41	3.84	3.4	0.44	11.45	
3.9:0.95:23	3.44	4.02	-0.58	-16.86	

FIGURE:

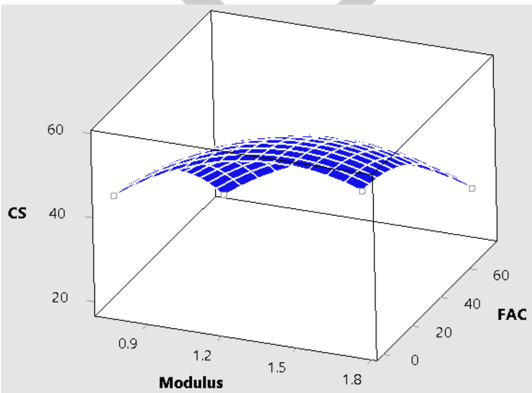


Figure 1: Surface plots of compressive strength with Activator modulus and Fly ash content

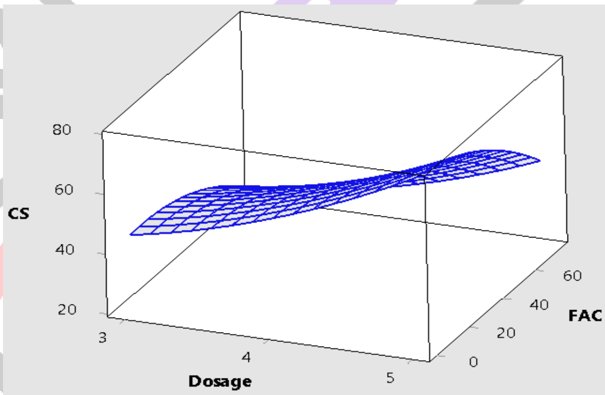


Figure 2: Surface plots of compressive strength with Sodium oxide dosage and Fly ash content

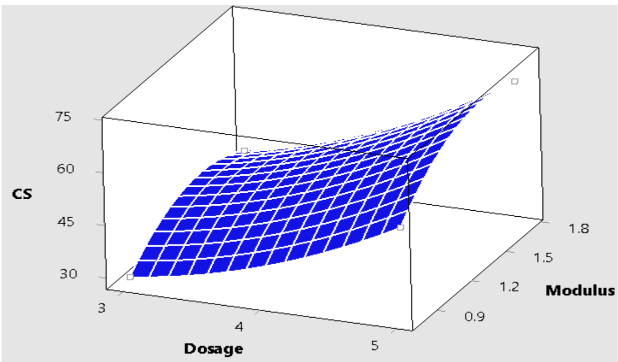


Figure 3: Surface plots of compressive strength with Sodium oxide dosage and Activator modulus

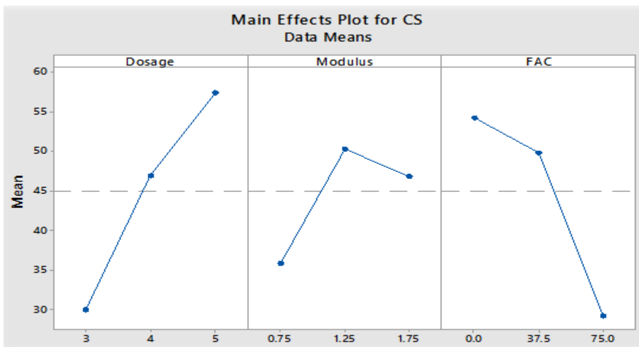


Figure 4: Main effect plots for compressive strength

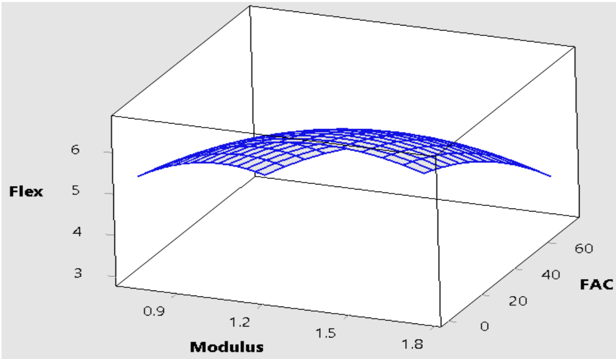


Figure 5: Surface plots of flexural strength with Activator modulus and fly ash content

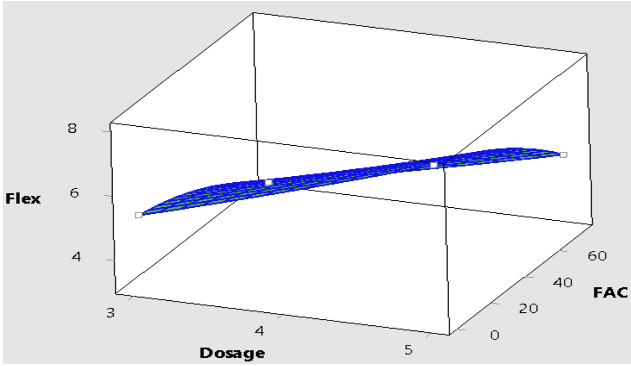


Figure 6: Surface plots of flexural strength with Sodium oxide dosage and fly ash content

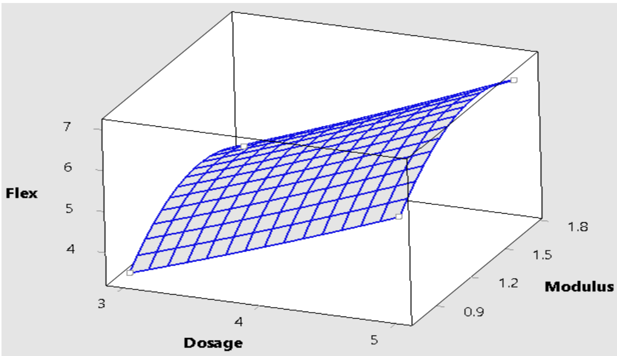


Figure 7: Surface plots of flexural strength with Sodium oxide dosage and Activator modulus

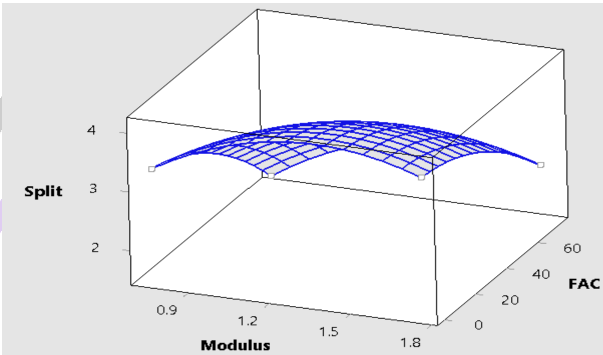


Figure 8: Surface plots of split tensile strength with Activator modulus and fly ash content

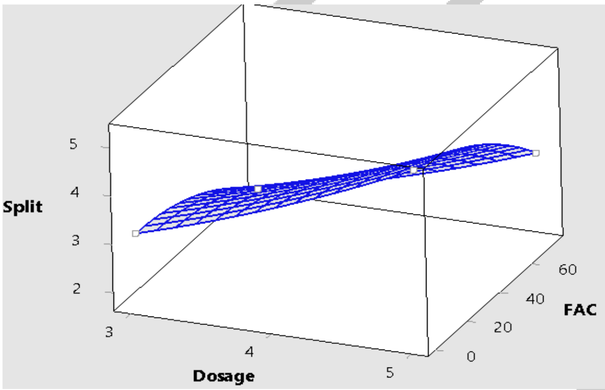


Figure 9: Surface plots of split tensile strength with Sodium oxide dosage and fly ash content

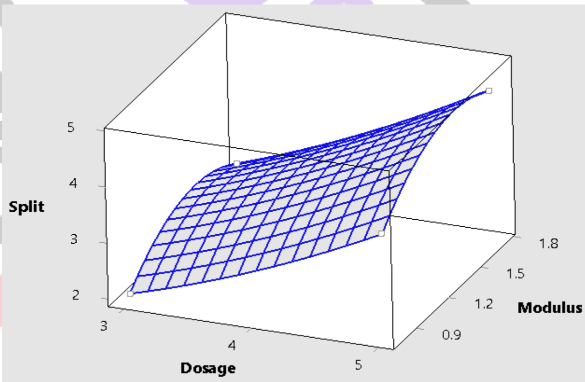


Figure 10: Surface plots of split tensile strength with Sodium oxide dosage and Activator modulus

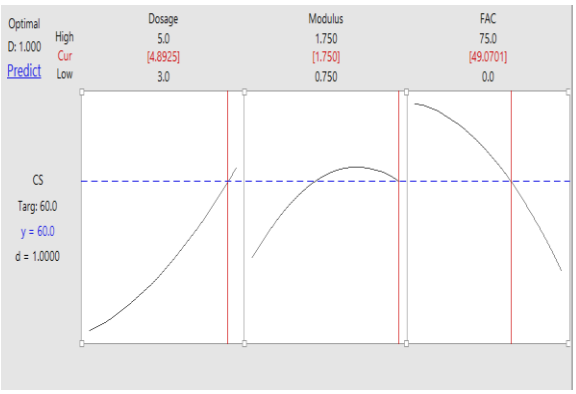


Figure 11: optimization plot for compressive strength

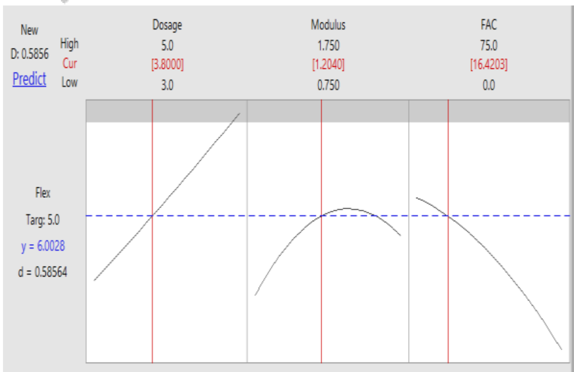


Figure 12: optimization plot for flexural strength

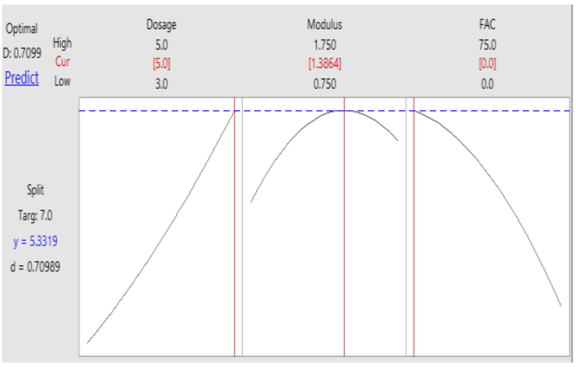


Figure 13: optimization plot for split tensile strength

CONCLUSIONS

Central composite design of experiments is used to develop the non-linear model with the parameters set at three levels. Once the models are developed, their statistical adequacy has been tested ANOVA test and coefficient of correlation values. It is to be noted that all the models developed are found to be statistically adequate. To validate the developed models, twenty test cases are examined and the deviations in predictions are determined. The results of this validation show that non-linear models developed for alkali activated slag concrete system has given better predictions for all the responses. The methodology and the regression models can be used in the foundries to know the response values for different combination of input parameters, without conducting experiments. This will assist the foundry men to set the process parameters, depending on their requirements.

The following are some of the conclusion drawn from the present investigation:

1. The strength properties of AASC and AASFC are influenced widely by the modulus and the sodium oxide dosage of the alkaline solutions. The use activator modulus of 1.25 in the alkaline activator provided the highest compressive strength for AASC with fly ash zero percent and AASFC mixes with fly ash 37.5 and 75%.
2. The compressive strength, flexural strength and split tensile strength value increases with increase in sodium oxide dosage.
3. The compressive strength value decreases with increase in fly ash contents and it is independent of fly ash content, when fly ash used above 75%
4. The strength of the AASC and AASFC depend on the sodium oxide dosage of the alkaline activator. Higher the sodium oxide dosage, higher the strength achieved.
5. The strength of the AASC and AASFC mixes decreased with the increased FA content.
6. Production of air cured AAS concrete will result in the reduction of OPC and in turn reduces carbon dioxide emissions.
7. A well planned alkali activated slag concrete mix design shows the less cost than traditional concrete.
8. Response surface methodology used only when there are 5 input parameters. More input parameters will give more number of trail mixes.
9. The validation of response surface methodology also checked and the average percentage variation is less than 5%. So acceptable.

On-going studies on the AASC and AASFC mixes

1) Study on durability properties such as Chloride Ion diffusion, resistance to magnesium sulphate attack, resistance to sulphuric acid.
2) Study on the flexural fatigue behavior of AASC and AASFC mixes.

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