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Study on Compressive Strength of Concrete using Nano silica by Design of Experiments

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Abstract
It is essential to conduct more number of experiments and more numbers of trials are involved in research works to find the optimum results. Taguchi method of design of experiments is very useful tool for optimizing the experimental design to get better output with minimum number of trials. The design of experiment (DOE) reduces the time and materials for conducting the experiments. Taguchi method is one of the statistical tools of partial factorial method using orthogonal array suggested and designed by Taguchi. The experiments were conducted on L4 and L18 Orthogonal array for M60 and M30 grade of concrete were used respectively and analysis were made to find S/N ratio(Signal to Noise ratio), main effects, ANOVA (Analysis of variance),optimum trial condition, total contribution from all the factors, current grand average performance and Expected result at optimum condition.

Keywords: Compressive strength, Optimization, Taguchi method, Design of experiment, S/N ratio (Signal to Noise ratio), ANOVA.

Introduction

Many research works are carried out by Nano technologist in wide fields such as electronic, electrical, mechanical, automobile, medical, agricultural, chemical, and civil and other streams of Engineering. Nanotechnology is one of the emerging fields and it helps in many engineering and science researches. Many application of nanotechnology can improve the performance and properties of traditional materials. The new materials are bringing out by different product to the infrastructure society with various forms of Nano materials such as nanoparticles, Nano fibres, nanotubes, nanowires and anticorrosive Nano coatings in the construction industry and it improves the performance of the structures as well as economy of the country. Nanotechnology also involves in many streams in civil engineering works such as construction materials, water purification, and energy consumption by solar cells and insulation, traffic engineering, soil improvement etc. The investigation attempt to evaluate the strength of high performance concrete with fly ash through well-defined experimental studies comprising mix design methodology and to study the effect of different trial condition that ensure higher strength. All the materials with Nano size of particles like Nano cement, Nano sand, Nano silica, Nano alumina, Nano Calcium oxide, Nano zinc oxide, Nano iron oxide increases the properties of each materials and enhance the strength and durability of concrete.

The effects of size of the Nanoparticles are playing a major role in civil engineering materials. If decreases the size of the Nano particles occupy the pores present in the cement, fine aggregate and coarse aggregate. The Nano particles filled in the voids presents in between the micro pores in the cement particles, thereby the strength of concrete increased (1). Nano silica is extensively used among all the other Nano particles which improves the cementitious and mechanical properties of concrete (2),(3). Nano particles can be used to enhance the strength properties in all the types of concrete such as light weight concrete, self-compacting concrete (4), air entrained concrete, no-fines concrete, floating concrete, high density concrete, high performance concrete etc., Nano silica has 99.5% of amorphous content which gives pozzolanic action by forming C-S-H gel(5). Amorphous Nano silica in concrete increases the compressive strength and reduce the pore structure and densify the micro structure of concrete due to its pozzolanic property and forming C-S-H gel by hydrated particles and it reduces the calcium leaching. (6-19).

Design of Experiments

Taguchi method of Design of Experiments is suitable for researchers to find many solutions by conducting few experiments and interaction studies can be possible by using this method. It is a statistical tool for optimize the strength of concrete using minimum number of trials suggested by Taguchi. It is a useful statistical tool to design the experiment to optimize the product and process design. Orthogonal array selected based on the parameters involved in the work and to conduct the experiment based on Taguchi suggested OA (Orthogonal Array).This orthogonal array is partial factorial method selected from full factorial design. In Taguchi method of design of experiments gives the effect of individual factor influence in the various ingredients in concrete mixture. Interaction studies are possible in this method.

Using Taguchi method in the experimental work and parameter design consists selected factors such as mineral admixture, water to binder ratio, curing type and time. The physical properties of concrete with the reducing capillarity coefficient, capillarity porosity also decreased. 10% of silica

fume and 5% of Blast furnace slag in concrete indicate more durable one as mentioned by BrahimTu et al. 2008(19). L18 orthogonal array selected in high strength self-compacting concrete consists of various factors and tests on compressive strength, splitting tensile strength, Ultrasonic pulse velocity, minimization of air content, water permeability and water absorption values for optimum level condition. Erdog an OZbay et al.(20) concluded that this method is suitable for optimizing the parameters design. Taguchi method used in recycled aggregate concrete for optimizing the mixture proportioning for electrical resistance and better compressive strength. Flow chart showing all the steps involved in the process of experimental works by using Taguchi method of design of experiments is given in Figure 1.

The optimum trial condition is determined to be 0.4 of W/C, 100% Recycled coarse aggregate, 15% recycled fine aggregate and 0% of slag for replacement as investigated by Hsiao, T.C et.al (22). L16 (4^5) orthogonal array chosen for Concrete mixture designed with 3 factors namely Water / Cementitious material(W/C) ratio, air entraining agent volume fraction in total aggregate. Analysis of variance is used by Zhang.N et.al (2011) (22)for analysing the experimental values. In Taguchi method there are 2 major designs of experiments such as Product design and Process design. Process parameter design of optimization for fly ash bricks. L9 Orthogonal array with 4 factors of 3 levels each. The estimated optimum values of the process parameters are water/binder ratio of 0.4, fly ash of 39%, coarse sand of 24%, and stone dust of 30% as experimented by Chaulia, P.K et al (23).

In present work statistically designed experiments are carried out as specified by an orthogonal array. Using Analysis of Variance (ANOVA), the percentage contribution of all the process control factors on the target compressive strength was calculated. Response characteristics were drawn for each factor using the main effects calculated from S/N ratio.

At the best levels of factors suggested by Taguchi method, the compressive strength achieved is more in M30 grade of concrete compared with M50 grade at 28 days of curing, which is an increase of 42.35 % over the strength achieved by the conventional method designed as per Indian standard specifications.

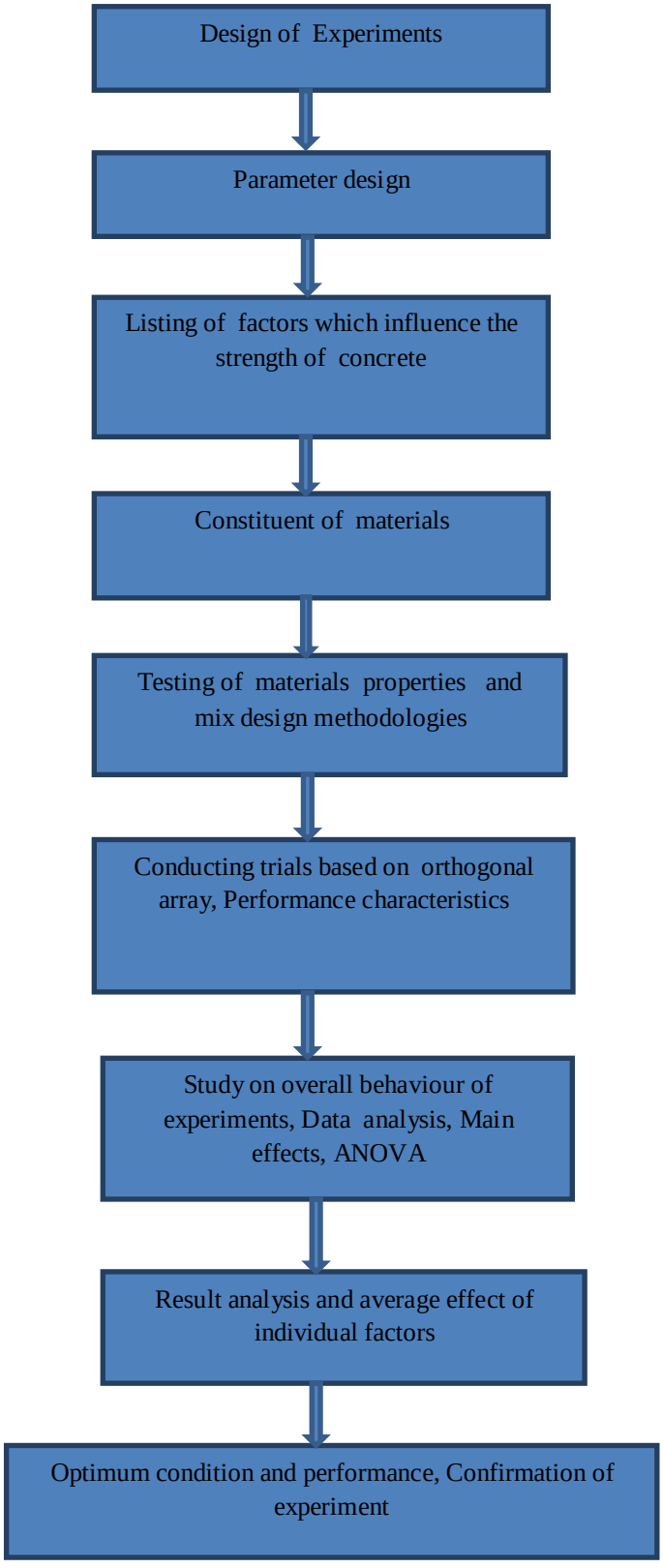

Fig. 1 Flow chart - Steps involved in the process of design of experiments using Taguchi method

Materials and Methods

Ordinary Portland Cement (43 grade), river sand as fine aggregate, granite as coarse aggregate, fly ash obtained from

Neyveli Lignite Corporation, rice husk ash, two different types of chemical admixtures were used namely Sulphonated Naphthalene Formaldehyde and Acrylic Polymer and Nano silica were also used in concrete mixture in colloidal form. Properties of materials used in concrete mixture and chemical composition in cement and Nano silica given in **Table No.1, 2 & 3** respectively.

Table.1 Specific gravity of materials used in experimental works

SL.No.	Physical properties	Specific gravity
1	Cement	3.16
2	Fly ash	2.74
3	Nano silica	1.22
4	Sulphonated Napthalene formaldehyde	1.24
5	Acrylic polymer	1.19
6	Rice husk ash	3.47
7	Sand	2.60
8	Coarse aggregate	2.80
9	Rock dust	3.64

As per IS 456(2000) size of the mould 150 x 150 x150mm were used. By using design of experiment L4, L18 Orthogonal array **(Table - 4)** chosen and cast concrete cubes based on levels given by Taguchi method. In present investigation two different grades of concrete M30 and M60 considered for comparing the results with conventional concrete. The two methods of design of experiments such as Process design and Product design involved in this work. The concrete cubes cast and tested in compression testing machine.

Table 2. Chemical Composition of Portland cement

Contents	Percentage in cement
SiO_2	20.9
Al_2O_3	4.60
Fe_2O_3	3.15
SO_3	3.60
CaO	62
MgO	2.00

Table 3.Chemical analysis of Nano silica (colloidal form)

Contents	Composition in %
SiO_2	99.4%
Na_2O	0.45%
Al_2O_3	0.075%
Sulphate	<0.1%
Fe (ppm)	25 %
Ca(ppm)	10 %
Zn,Pb,Cu (ppm)	< 0.1

Table 4. L18 Orthogonal array

No. of trials	F 1	F 2	F 3	F4	F 5	F 6	F 7	F 8
Trial 1	1	1	1	1	1	1	1	1 Orthogonal array L18
Trial 2	1	1	2	2	2	2	2	2
Trial 3	1	1	3	3	3	3	3	3
Trial 4	1	2	1	1	2	2	3	3
Trial 5	1	2	2	2	3	3	1	1
Trial 6	1	2	3	3	1	1	2	2
Trial 7	1	1	1	2	1	3	2	3
Trial 8	1	1	2	3	2	1	3	1
Trial 9	1	1	3	1	3	2	1	2
Trial 10	2	1	1	3	3	2	2	1
Trial 11	2	1	2	1	1	3	3	2
Trial 12	2	1	3	2	2	1	1	3
Trial 13	2	2	1	2	3	1	3	2
Trial 14	2	2	2	3	1	2	1	3
Trial 15	2	2	3	1	2	3	2	1
Trial 16	2	1	1	3	2	3	1	2
Trial 17	2	1	2	1	3	1	2	3
Trial 18	2	1	3	2	1	2	3	1

The above table shows that the control factors for M30 grade of concrete and their levels which is used to conduct the experiments to optimize the strength of concrete by reducing the number of trials by partial factorial method.

Experimental Results:

Table 5. Control factors for M30 grade of concrete

S.No.	Factors	Level 1	Level 2	Level 3
1	Curing Type	Water	Hot Air	----
2	Coarse Aggregate	Normal	Graded	----
3	Cement / Fly ash	100/0	75 /25	50 /50
4	W/C Ratio	0.35	0.42	0.45
5	Sand / Rock Dust	100/0	75 / 25	50 / 50
6	Nano Silica	1%	1.5%	2%
7	Sulphonated napthalene Formaldehyde	0%	0.5%	0.75%
8	Acrylic Polymer	0%	0.5%	0.75%

Table 6.Trial Condition for M30 grade of concrete (4th Trial in an orthogonal array)

Factors	Level Description	Level
Curing type	Water	1
Coarse aggregate	Graded	2
Cement/Fly ash	100/0	1
W/B ratio	0.35	1
Sand/Rock dust	75/25	2

Table 8. Main Effects of the levels and factors - M30 grade of concrete

Sl. No.	Factors	Level 1	Level 2	Level 3	L2-L1
1	Curing type	29.67	26.93	0	-2.74
2	Coarse aggregate	27.78	29.33	0	1.545
3	Cement /Fly ash	31.67	28.36	24.86	-3.31
4	Water Cement ratio	29.11	28.28	27.50	-0.831
5	Sand / rock dust	28.02	28.98	27.915	-0.96
6	Nano silica	28.27	27.72	28.92	-0.55
7	Sulphonated Naphthalene	27.77	28.55	28.77	-0.973
8	Acrylic polymer	28.32	28.00	28.58	-0.321

Table 7. Test results for M30 grade concrete

SL.No.	Compressive strength (N/mm^2) 7^{th} day	28^{th} day
1	24.1	**40.20**
2	23.83	33.84
3	9.27	23.07
4	26.43	**54.45**
5	17.12	29.04
6	8.99	17.93
7	37.73	**45.32**
8	16.61	29.00
9	9.49	16.28
10	10.93	23.43
11	17.16	22.22
12	10.49	13.00
13	29.96	**40.26**
14	21.23	22.26
15	12.10	25.00
16	14.41	28.6
17	21.34	23.10
18	9.20	13.31

Table 9. Optimum Trial Condition

S.No.	Factors	Level Description	Level	Contribution
1	Curing type	Water	1	1.369
2	Coarse aggregate	Graded	2	1.029
3	Cement /Fly ash	100/0	1	3.371
4	Water Cement ratio	0.35	1	0.851
5	Sand / rock dust	75/25	2	0.677
6	Nano silica	2%	3	0.615
7	Sulphonated Napthalene	0.75%	3	0.475
8	Acrylic polymer	0.75%	3	0.283

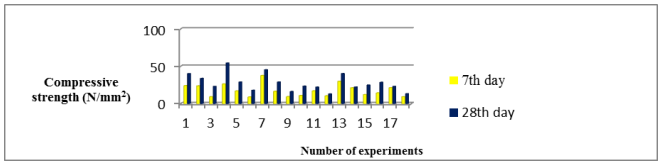

Fig. 2 Compressive strength of M30 grade of concrete

Table 5 & 6 Shows that the parameters used in the experiments with various levels and ingredients of concrete mixture respectively, for the trial No.4 the levels chosen from L18 Orthogonal array for conducting the experiments it gives better result than conventional concrete and other trials. **Table 7.** Shows the compressive strength of all 18 trials. Among all the trials, 4^{th} trial gives optimum result and it shows that the compressive strength is 35 % more than compressive strength of conventional concrete. **Table 8**. Gives the individual effects of individual factors in concrete mixture with their levels, main effects calculated using S/N ratio, It is calculated by using the following formulae**.**

$S/N = -10\log_{10}(MSD)$

$MSD = (1/y_1^2 + 1/y_2^2 + 1/y_3^2 + \ldots\ldots\ldots\ldots 1/y_n^2)/n$

y_1, y_2, y_3 - Results of experiments observations

m - Target value of results

n - Number of representation (y_1)

Table 9 Gives the optimum levels among the different levels which is considered for individual factor, from the main effects calculation total Contribution from all factors = 8.634, Current grand average of performance =28.299, Expected result at optimum condition =36.933

S. No.	Factors	DOF (F)	Sum of squares (S)	Variance (V)	Pure sum (S)	Per cent (P)
1	Fly ash	1	0.069	0.069	0.069	28.64
2	Nano silica	1	0.008	0.008	0.008	3.68
3	Super plasticizer	1	0.163	0.163	0.163	67.68
Total		3	0.241			**100%**

Table 10. Control Factors for M60 Mix Concrete

SL.NO.	Factors	Level 1	Level 2
1.	Fly ash	30%	40 %
2.	Nano silica(By weight of binder)	2%	3 %
3.	Super plasticizer (By weight of binder)	0.5%	1.0 %

Table 11. Compressive strength at 28th day and S/N ratio

Mix	7th day (N/mm2)	14th day (N/mm2)	28th day (N/mm2)	S/N ratio
Control concrete	50.12	62.41	70.47	----
T1	67.34	70.5	76.43	37.664
T2	60.74	67.74	79.23	37.976
T3	61.25	69.44	**82.54**	38. 332
T4	64.22	65.45	78	37.836
			79.049 N/mm2	**37.952**

Table12.Main Effects of the levels and factors M60 grade

Factor	Level 1	Level 2	Level 2 - Level 1
Fly ash	37.82	38.084	0.264
Nano silica	38.00	37.906	- 0.92
Super plasticizer	37.75	38.154	0.404

Table.13 Analysis of variance (ANOVA)

Factor	Level Description	Level	Contribution
Fly ash	40%	2	0.131
Nano silica	2%	1	0.046
Super plasticizer	1%	2	0.202

Table 10. Shows that the factors used and their levels for M60 grade of concrete and compressive strength of concrete at 7, 14 and 28 days tested also calculated S/N ratio tabulated in Table 11. The main effects of the factor for each level are mentioned in Table 12. For M60 grade of concrete. Table 13. Shows the analysis of variance of M60 grade of concrete and individual contribution of each factors which are considered in this work such as fly ash, Nano silica, and super plasticizer. There is no error in this work denotes the contribution of all the factors combindly reaches 100%. Similarly it can be extend to do the experiments for interaction of all the ingredients involved in the strength of concrete

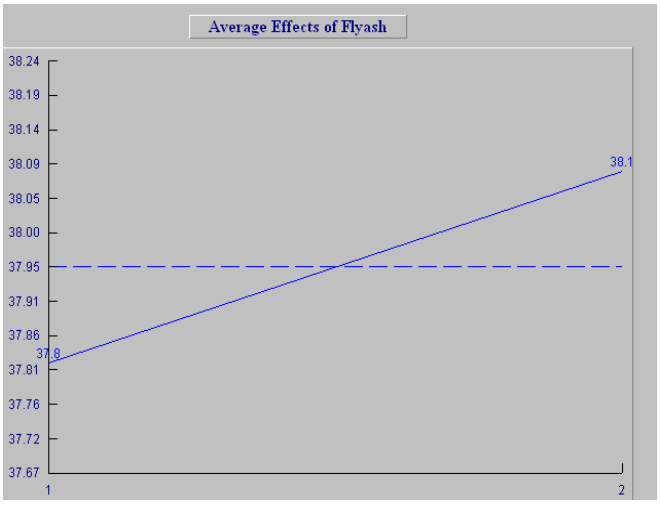

Fig 3. Effect of fly ash on various levels

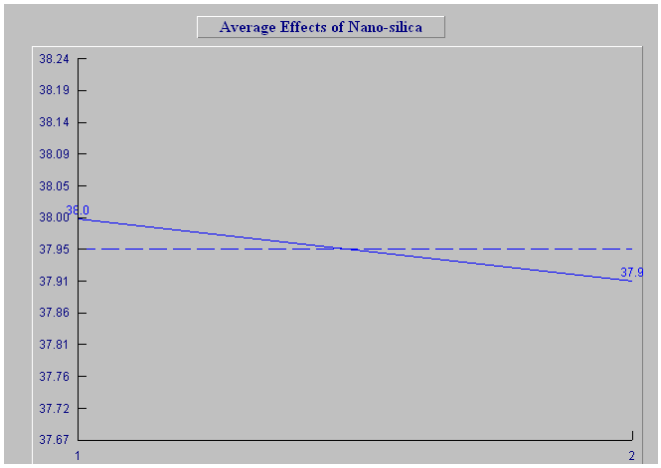

Fig 4. Effect of Nano silica on various levels

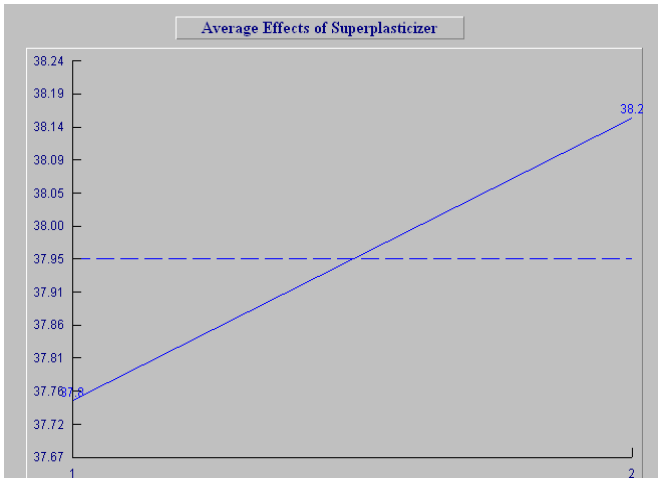

Fig 5. Effect of Superplasticizer on various levels

X -Axis= Number of levels:
Y- Axis = Average effect of Factors (S/N ratio)

Table 14. Optimum Trial condition

Factor	Level Description	Level	Contribution
Fly ash	40%	2	0.131
Nano silica	2%	1	0.046
Super plasticizer	1%	2	0.202

Table.14 shows the optimum level of the individual factors and their contribution in the strength of concrete
Total Contribution from all factors: 0.379,
Current grand average of performance: 37.952,
Expected result at optimum condition: 38.331.

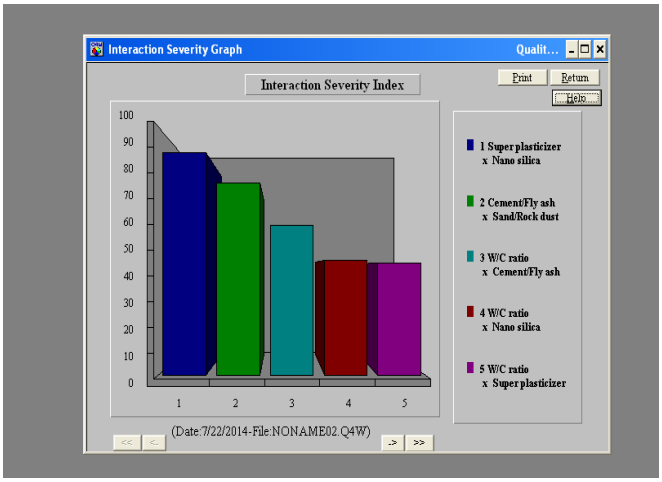

Fig. 6 Interaction Severity Index for M30

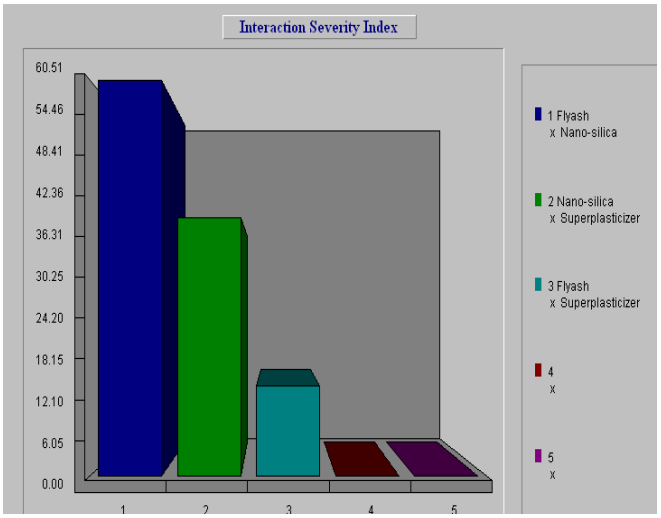

Fig. 7 Interaction severity Index for M60

Results and discussions

To enhance the compressive strength of concrete using Nano silica with different % of replacement of cements and used as a super plasticizer and replacement of cement with fly ash. The study includes evaluation on the hardened concrete property namely compressive strength of concrete using Nano silica with fly ash. The testing will be carried out as per the recommendations of ASTM. In M60 grade of concrete, L4 orthogonal array used and factors which involved in the work are Fly ash, Nano silica, Super plasticizer with two different levels such as 30% and 40% of replacement of cement with fly ash. 2% and 3% Nano silica and 0.5% and 1% Super plasticizer. Among the 4 trials 3rd trial gives better compressive strength it increases 24% more than target compressive strength for M60 grade. Main effects for the factors which considered in this study are indicating the influence of individual factors of materials in the concrete mixtures.

ANOVA gives the percentage contribution of individual factors in concrete strength. In M30 grade of concrete, L18 Orthogonal array was used and factors which considered mentioned in Table 5. Among the 18 trials 4th trial gives better compressive strength and it increases 47.16% more than target compressive strength for M30 grade.

Interaction Analysis of individual factors

In Taguchi method, it is possible to find the interaction effect of individual factors with each and every level of the factors which are considered for analysis in this work. From the interaction analysis, optimize each and every factor with various levels. From L18 orthogonal array 28 interactions obtained by Taguchi method. From the interaction analysis modifies the factors and conducted experiments and reduces the standard deviation.

Conclusion:

- Taguchi method of design of experiment is most suitable method for researchers to reduce the number of trials to optimize the strength properties and save time and materials.
- The Optimum results obtained by Taguchi method is more than Target Compressive strength of conventional M30 and M60 grade of concrete.
- Current grand average performance can be optimized and the expected result at optimum condition also can be determined by using Taguchi method, optimize the trials and possible to increase 30.51% of grand average performance of concrete strength.
- L4 orthogonal array in M60 grade of concrete, 3rd trial among 4 trials gives better compressive strength. It is 24% more than target compressive strength.
- L18 orthogonal array in M30 grade of concrete, out of 18 trials 4th trial gives better compressive strength result. It is 47.16% more than target compressive strength.
- ANOVA for M60 grade of concrete (Table 13) obtained 100% contribution without any error indicates the levels chosen for their factors are exactly accurate based on the strength of concrete.

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References:

[1] Zhang M.H, Islam J., 2012, "Use of Nano silica to reduce setting time and increase early strength of concrete with high volume fly ash or slag", Construction of building materials. Vol -29, pp.573-80.

[2] Singh L.P, Karade.S.R., 2013, "Beneficial role of Nano silica in cement based materials - A review", Construction and Building materials 47, pp.1069-1077.

[3] Monica J. Hanus, Andrew T. Harris, 2013, "Nanotechnology innovations for the construction Industry", Progress in Materials Science 58, pp.1056 –1102.

[4] Quercia. G, Spiesz. P, 2014, "SCC modification by use of amorphous Nano silica", cement &concrete composites 45, pp. 69-81.10.

[5] Hui Li, Hui-gang Xiao, Jie Yuan, Jinping Ou, 2004,"Microstructure of cement mortar with Nanoparticles", Harbin Institute of Technology, School of Civil Engineering, 150090 People's Republic of China, Composites: Part B 35, pp. 185–189.

[6] Bjeorn streom, L. Beorjesson b, I. Panasa, 2004, "Accelerating effects of colloidal Nano-silica for beneficial calcium-silicate-hydrate formation in cement", Chemical physics letters, Vol.392, 1-3, pp.242-248.

[7] Konstantin Sobelev, Ismael Flores, Roman Hermosillo, Leticia M. Torres – Martinez, 2006, "Nanomaterials and nanotechnology for High performance cement composites", pp.91-118.

[8] K.Sobolev, I.Flores,L.M. Torres-Martinez,P.L.Valdez, E.Zarazua, and Cuellar, 2009, "Engineering of SiO_2 Nanoparticles for optimal Performance in Nano Cement based Materials", MRS Proceedings1276, pp.139 -148,Nanotechnology in construction 3.

[9] Konstantin Sobolev, Elvira Zarazúa M., Leticia M. Torres-Martínez, Ismael Flores, 2010, "Preparation of SiO_2 Nano particles using for their application cement materials", Materials research society symposium proceeding vol. 1276, ISBN 978-1-60511-253-264.

[10] Konstantin Sobolev, 2008, "Nano materials and nanotechnology for high performance cement composites", American concrete institute, International concrete Abstract portal, Vol-254, pp. 93-120.

[11] Jonathan S. Belkowitz and Dr Daniel Armentrout, 2010, "An investigation of Nano silica in the cement hydration process", Concrete sustainability conference, National Ready Mixed Concrete Association pp. 121-132.

[12] Luciano Senffa, Dachamir Hotzaa,Wellington L. Repetteb, Victor M. Ferreirac and Joao A. Labrinchad 2010, "Conducted experiments on Design on Mortars with nano-SiO_2 and micro-SiO_2",Construction and building materials -24, pp. 1432-1437.

[13] Luciano Senff, 2009, "Effect of Nano silica on rheology and fresh properties of cement pastes and mortars", Construction and Building Materials 23, pp. 2487 - 2491.

[14] Shadi Riahi, Ali Nazari, 2012, "The effect of Nanoparticles on early age compressive strength of ash based geopolymers", Ceramics international- 38, pp.4467-4476.

[15] Alaa Rashad, 2014, "A comprehensive overview about the effect of Nano SiO_2 on some properties of traditional cementitious materials and alkali activated fly ash", Construction and Building materials 52, pp.437- 464.

[16] Barissimsek, Yusuf Tancel, Emir.H simsek, 2013, "A TOPSIS based Taguchi optimization to determine optimal mixture proportions of the high strength self-compacting concrete", chemometrics and intelligent laboratory systems 125, pp.18-32.

[17] Ayan.E, O.Saatcioglu, L.Turanli, 2011, "Parameter Optimization on compressive strength of steel fiber reinforced high strength concrete", Construction and Building materials 25, pp. 2837 – 2844.

[18] Jeng-Ywan Shih, Ta-Peng Chang and Tien-Chin Hsiao, 2006, "Effect of Nano silica on characterization of Portland cement composite", Material science Engineering, Vol.424, pp. 266- 274.

[19] Ibrahim Turkmen, Ru Stem Gu, Cafer C-eliKb, 2008, "A Taguchi approach for investigation of some physical properties of concrete produced from mineral admixtures", Building and Environment 43, pp. 1127-1137.

[20] Erdog an OZbay, Ahmet Oztas, Adil Baykasoglu, Haken Ozbebek, 2009, "Investigating mix proportions of high strength self-compacting concrete by using Taguchi method", Construction and Building Materials 23, pp.694-702.

[21] Hsiao,T.C. Chang, T.P., Tsay, D.S., Yang, T.R., 2011, "Study on mix proportion method and evaluation optimal engineering properties of recycled aggregate concrete", International Conference on Civil Engineering and Building Materials, Vol.22, No.4, pp.399-409.

[22] Zhang, N., Lu, A., Cui, P., Xu, Y. 2011, "Investigating properties of haydite concrete by using Taguchi method", Advanced Materials Research 05, pp. 261-263,242-246.

[23] Chaulia, P.K., Das, R., 2008, "Process parameter optimization for fly ash brick by Taguchi method", Materials Research, pp. 770-789.

[24] Quercia.G, Spiesz.P, Ji.T., 2005, Preliminary study on the water permeability and microstructure of concrete incorporating Nano-SiO_2, Cement concrete research 3510, pp. 1973-77.