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Rubberized Geopolymer Concrete: Application of Taguchi Method for Various Factors

Salmabanu Luhar, Ismail Luhar

Abstract**:** ***The effect of different factors on the compressive strength of fly ash based rubberized geopolymer concrete has been established using Taguchi method. The factors include alkaline solution/fly ash ratio; ratio of Na_2SiO_3/NaOH, molarity concentration of NaOH, temperature of curing, time period for curing, water content, rest period and amount of superplasticizer as an additional material are considered. Total twenty-seven experiments have been conducted in accordance with Taguchi orthogonal array L_{27}. Different mixtures of the fly ash based rubberized geopolymer concrete have been examined for compressive strength at seven days. ANOVA (Variance Analysis) method was used to evaluate the influence of each factor and to identify the test mixture with the highest compressive resistance. The results of experiments show that the alkaline-to-fly ash mixture is 0.35, Na_2SiO_3/NaOH 2.5, 14 M NaOH, 90°C temperature for curing, 48-hour curing time, 20% water content, 1 day resting period, and 2 percent addition of superplasticizer acquires the greatest compression strength of 59.08 MPa. The curing temperature was also identified as the main factor influencing a rubberized fly ash-based geopolymer concrete's compression strength.***

Keywords**:** ***Geopolymer concrete; Taguchi method; Compressive strength; Waste tyre, ANOVA.***

I. INTRODUCTION

Concrete is one of the most important construction products used in building worldwide, next to water [1-4]. Owing to a burgeoning population and development programs, a great boost in growth of construction industry is noted that ultimately resulted in a demand for prodigious quantities of concrete worldwide. Consequently, ordinary Portland cement production has augmented in the recent years. India is the world's second-largest cement producer. The Indian production of OPC was around 390 million metric tons in 2014 that put it to second highest position in the world. In addition, India is anticipated to meet a cement requirement of 550 million tons per year by 2025 [4-7]. Unfortunately, a ton of carbon dioxide (CO_2) produced in one ton of cement emanates, a main greenhouse gas, into the atmosphere increasing global warming [8,9]. Presently, the world's cement industries contribute around 7% of world CO_2 emissions [10-12]. Therefore, it is highly desirable to produce a sustainable concrete that helps to mitigate the carbon footprint of concrete. In other words, a sustainable, user and eco-friendly concrete can serve the purpose.

Geopolymer is a novel inorganic binder produced by the geopolymerisation reaction between source materials (having higher silica and alumina content) of geological origin and alkaline solution in highly alkaline conditions at low temperatures and atmospheric pressure [13,14]. Geopolymer concrete demonstrates excellent properties of resistance against sulphate, chloride, and acid attacks [15-21]. In comparison with regular Portland cement concrete, it has strong prospective applications in the encapsulation of toxic solid waste and heavy metals [22]. It functions as a fire resistant as it shows excellent high-temperature stability [23-26]. On the other side, Disposal of waste tire becomes a dilemma, however, since it is a very complicated chemical structure that makes waste rubber tyre recycling a challenging job. Furthermore, the destruction of tyre rubber in regions close to habitats creates health and environmental risks. In the current situation, the conservation of restricted natural resources of sand- an essential constituent of concrete is highly essential. Researchers have tried in the past for a replacement of a small percentage of sand in a cement concrete by rubber [27]. It is desirable to produce the rubberized geopolymer concrete by combination of waste rubber fibers, fly ash and alkaline solution that gets synergy advantages of two different geopolymeric concretes – a fly ash based geopolymer concrete and rubberized fly ash based geopolymer concretes.

II. PREVIOUS RESEARCH

Dr. Genichi Taguchi developed Taguchi method [28]. It is an effective and systematic way to design experiments to study the effects of various parameters on the process results. It is used to study the impact of many parameters with few experiments [29].

In the past, several works on using the Taguchi technique have been performed to study the impacts of different parameters on concrete properties. [30-32]. Certain scientists have used this technique to design tests and study the impacts of various variables in geopolymer concrete's characteristics [33-37]. For instance, Olivia and Nikraz [33] studied effect on fly ash based, geopolymers by the Taguchi technique, of parameters such as aggregate content, alkaline solution, sodium hydroxide proportion, and the process of curing. At 28 days with greater tensile and flexural strength, less expansion and drying shrinkage the peak compressive strength of 55 MPa was recorded.

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***** Correspondence Author

Salmabanu Luhar*, Institute of Mineral Resources Engineering, National Taipei University of Technology, Taipei, Taiwan.

Malaviya National Institute of Technology, Rajasthan, India,

Ismail Luhar, Shri Jagdishprasad Jhabarmal Tibrewala University, Rajasthan, India.

They confirmed that geopolymer concrete is durable and is a feasible OPC concrete alternative. Nazari et al. [34] employed Taguchi technique to design compressive strength of OPC based geopolymer concrete. They explored the impact on compressive strength of OPC-based geopolymer concrete of several variables such as NaOH concentration, NaOH sodium silicate ratio, Alkaline activator ratio with cement, temperature for curing, curing time and extra waters. By ANOVA assessment, the NaOH-14 M, Na_2SiO_3 to NaOH ratio 1.0 specimens at room temperature, alkaline activator with a binder ratio of 0.42 were found to have the greatest compressive strength over 28 days. In another research of Nazari et al. [35], Taguchi L_{32} array was used and gene expression programming (GEP) model was developed to predict the compressive strength of OPC based geopolymer concrete. Mijarsh et al. [36] optimized factors by L_{25} Taguchi orthogonal array in their study. They divided six factors into two parts wherein first part included $Ca(OH)_2$, silica fume, $Al_2(OH)_3$ etc.- additive materials and second part included Concentration of NaOH, NaOH sodium silicate ratio, alkaline activator- solid material ratio, etc.They reported that binding phase consist of N-A-S-H (Na_2O- Al_2O_3- SiO_2-H_2O) gel and C-S-H (Calcium silicate hydrate) gel. Bagheri and Nazari [5] developed class C type fly ash based geopolymer concrete with granulated blast furnace slag aggregate. They comprised four factors namely total aggregate content, concentration of NaOH, time for curing and temperature. They reported that highest compressive strength was achieved with 12M NaOH concentration, 90°C curing temperature, 16 hr curing time and 30% aggregate content at 2nd and 7th day. In order to determine the optimum amount of each factor as curing time, temperature curing and NaOH concentration of rice husk and fly ash derived geopolymer concrete through Taguchi as well as ANOVA technique studied by Richi et al. [37]. By applying light and medium NaOH concentrations for all samples, they accomplished optimal strength on the 7th day.

No study, to the best of knowledge of authors, is encountered till date for analysing the effect of various factors on properties of rubberised geopolymer concrete. Therefore, the effect of various factors on compressive strength of rubberised geopolymer concrete, which is a highly sustainable replacement of OPC, has been studied in this work. Curing time, Na_2SiO_3/NaOH ratio, liquid alkaline to fly ash ratio, superplasticizer, resting time, water content, NaOH content and the curing temperatures are regarded. All these variables and their impacts on the compression strength of concrete are experimentally difficult to consider individually. The Taguchi method has therefore been used to assess the impact of those factors in the compression strength of rubberized geopolymer concrete and thus to identify the most optimal quantity for the composition of rubberized geopolymer concrete. In the evaluation of the ranking of the beneficial variables of the rubberized geopolymer concrete, ANOVA (analysis of variance) technique was employed, and optimum mixed ratio was established after seven days. One of the biggest benefits of Taguchi is that it minimizes the number of tests that lead to minimum test costs.

III. EXPERIMENTAL PROGRAMME

A. Materials

Fly ash

As a source material, low calcium class F fly ash was used.

Sodium Hydroxide (NaOH)

Sodium hydroxide flake form (NaOH) was used with purity of 98%. These flakes were dissolved in water to create the necessary molarity solution.

Sodium Silicate (Na_2SiO_3)

Sodium Silicate Water Glass (Na_2SiO_3) has been used as an activator of alkaline.

Aggregate

The river sand with a maximum size of 4.75 mm was locally accessible used as fine aggregate. Crushed stone was used for coarse aggregate use with a maximum size of 20 mm. Properties of both the fine and coarse aggregate are shown in Table I.

Table- I: Fine aggregate and coarse aggregate properties values

Properties	Fine aggregate	Coarse aggregate
Specific gravity	2.6	2.67
Water absorption (%)	0.8	0.5
Moisture content (%)	0.15	Nil
Fineness modulus	2.5	--
Zone	II	--

Rubber Fibres

Locally available waste rubber particles were used as 10% substitution of fine aggregate.

Superplasticizer

It was observed that any rise in rubber fibre particles in geopolymer concrete mix lead to reduction in the slump value of geopolymer concrete. Therefore, to achieve desired slump value, Naphthalene sulphonate based plasticizer was used as admixture. Specifications of superplasticizer are relative density 1.26 ± 0.02 at 25°C, pH> 6 and content of chloride ion < 0.2%.

IV. TAGUCHI METHOD FOR EXPERIMENTAL DESIGN

The purpose of this research was for the compression resistance of rubberized geopolymer concrete to be determined by various variables. The current research includes variables such as cure time, ratio of Na_2SiO_3/NaOH as well as alkaline fluid / fly ash ratio, plasticizer, period of rest, water content, concentration of NaOH and curing temperature for Taguchi method of analysis. Each variable was considered at three levels. The variables and levels of each factor are shown in Table II.

Table- II: Factors and their levels

Factors	Level-I	Level-II	Level-III
Factor-A: Ratio of Alkaline liquid to Fly ash	0.3	0.35	0.4
Factor-B: Ratio of Sodium silicate to NaOH concentration	1.5	2.0	2.5
Factor-C: Concentration of NaOH (M)	10M	12M	14M
Factor-D: Temperature for curing (°C)	60	75	90
Factor-E: Cure Time (hr)	24	48	72
Factor-F: Water content (%)	15	20	25
Factor-G: Period for rest (Days)	0	1	2
Factor-H: Plasticizer (%)	2	3	4

This study was used full factorial design, Orthogonal arrays, L_{27} (3^{13}) established by Taguchi method [28]. Table III provides an Orthogonal array for total 27 mixes of rubberized geopolymer concrete. In order to define the variety of each factor, primary tests were performed. Table IV shows the variables for each of the mixes. In order to assess the compressive strength, a total of 27 rubberized geopolymer concrete mixtures (T1-T27) were used. The experiment was performed on three numbers of standard size cube samples for each mixture.

V. RESULT ANALYSIS AND DISCUSSION

In the present study, the result data involve three runs to select optimum level. A signal to noise ratio (S/N ratio) analysis was used to determine the value of the control factor on the compressive strength of the rubberized geopolymer concrete. For Taguchi technique, there are three kinds of S/N ratio,

I. Lower is better,
II. Normal is better,
III. Higher is better.

Since, the target of the study is to achieved highest compressive strength therefore third type (higher is better) was used. According to this type,

$$\frac{S}{N} = -10 \log\left(\frac{1}{N}\sum_{i=1}^{n}\frac{1}{Yi^2}\right) \tag{1}$$

Where n is the amount of repetitions and Y represents the results of measurement under the same experimental circumstances. Y is the compressive strength of the geopolymer concrete based on fly ash [38].

Average compression strength of 27 rubberized geopolymer concrete test mixes at the age of seven days is shown in Fig. 1. T-8 mix with an alkaline liquid to fly ash ratio of 0.3, a sodium hydroxide to a sodium silicate ratio of 2.5, a NaOH of 14 M, a cure temperature of 90℃, a cure time of 48 hours, a rest period of one day and the superplasticizer of 2% obtained the maximum compressive strength of 59.08 MPa. The increase of the strength of the compression indicates an increase of the rate of geopolymerisation. The results of ANOVA show that the cure temperature affects the compressive strength significantly. This is mainly due to the heat that the method of geopolymerization needs to be completed.

Table III provides the ratio S/N for the calculated trial mixes provided the condition of larger is better. The maximum S/N ratio for T-8 mix between all 27 combinations is shown in Table III, showing that T-8 Mix provides the highest compressive force in all combinations of rubberized geopolymer concrete.

Fig.2 shows that an increase in ratio of alkaline liquid to fly ash (factor-A) from 0.3 to 0.35 increases the compressive resistance of concrete whereas a further rise in the rate the compressive resistance was reduced. Rising the compressive strength of rubberised concrete as Sodium silicate to sodium hydroxide ratio (factor-B), concentration of NaOH (factor-C) and cure temperature (factor-D) increases. Cure time (factor-E) for rubberized geopolymer concrete samples were increased up to 72 hrs, and it was found that any increase in curing time beyond 48 hours reduces the strength owing to water evaporation from the surface of the specimen. For the production of rubberized geopolymer concrete, a limited water content is needed because water is expelled when the alkaline solution, water and the source material are reacted. A water content (factor- F) up to 25% of water was found to help in producing dense concrete without loss in strength. It was further observed that an addition of superplasticizer (factor-H) up to 3% increases the compressive resistance of geopolymer concrete.

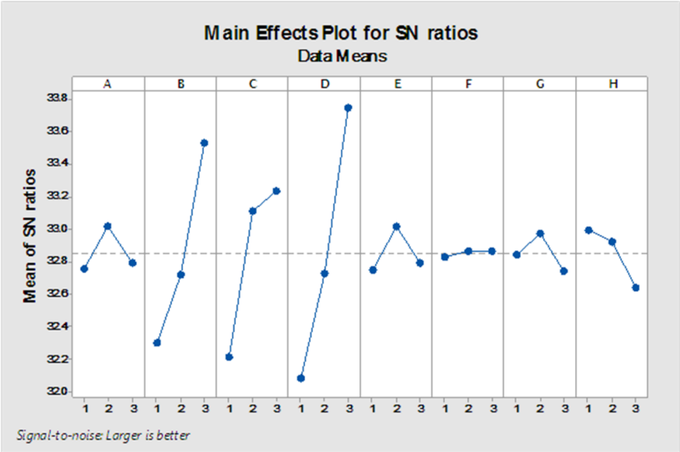

Fig.2. Effect of each factor on compressive strength of rubberized geopolymer concrete

ANOVA Table V, shows that ratio of sodium silicates to NaOH, concentration of NaOH and cure temperature respectively, are the highest contribution variables. Table VI shows the ranking of these 8 variables.

The optimal value of each factor, with the Taguchi technique, is indicated in Table VII.

The results demonstrate that the Taguchi technique is appropriate for obtaining maximum compressive resistance for rubberized concrete geopolymer.

Table- III: Taguchi Orthogonal array (L_{27})

Trials	Factor-A	Factor-B	Factor-C	Factor-D	Factor-E	Factor-F	Factor-G	Factor-H	Compressive strength (N/mm^2)	S/N ratio
T-1	1	1	1	1	1	1	1	1	34.85	30.84406
T-2	1	1	1	1	2	2	2	2	36.00	31.12605
T-3	1	1	1	1	3	3	3	3	33.11	30.39918
T-4	1	2	2	2	1	1	1	2	43.71	32.81162
T-5	1	2	2	2	2	2	2	3	42.59	32.58615
T-6	1	2	2	2	3	3	3	1	44.00	32.86905
T-7	1	3	3	3	1	1	1	3	51.26	34.19557
T-8	1	3	3	3	2	2	2	1	59.08	35.42881
T-9	1	3	3	3	3	3	3	2	53.18	34.51497
T-10	2	1	2	3	1	2	3	1	48.83	33.77373
T-11	2	1	2	3	2	3	1	2	49.00	33.80392
T-12	2	1	2	3	3	1	2	3	46.11	33.2759
T-13	2	2	3	1	1	2	3	2	41.35	32.32951
T-14	2	2	3	1	2	3	1	3	42.00	32.46499
T-15	2	2	3	1	3	1	2	1	43.11	32.69156
T-16	2	3	1	2	1	2	3	3	41.35	32.32951
T-17	2	3	1	2	2	3	1	1	46.11	33.2759
T-18	2	3	1	2	3	1	2	2	45.59	33.17739
T-19	3	1	3	2	1	3	2	1	41.18	32.29373
T-20	3	1	3	2	2	1	3	2	42.26	32.51859
T-21	3	1	3	2	3	2	1	3	43.00	32.66937
T-22	3	2	1	3	1	3	2	2	45.63	33.18501
T-23	3	2	1	3	2	1	3	3	44.00	32.86905
T-24	3	2	1	3	3	2	1	1	43.11	32.69156
T-25	3	3	2	1	1	3	2	3	44.63	32.99254
T-26	3	3	2	1	2	1	3	1	45.00	33.06425
T-27	3	3	2	1	3	2	1	2	43.83	32.83543

Table- IV: Factors and variables of trials

Trial Mixes	Ratio of Alkaline to Fly Ash content (Factor-A)	Ratio of Sodium silicate to NaOH Concentration (Factor-B)	Concentration of NaOH (M) (Factor-C)	Temperature for cure (°C) (Factor-D)	Cure Time (hr) (Factor-E)	Water Content (%) (Factor-F)	Period for rest (day) (Factor-G)	Plasticizer (%) (Factor-H)
T-1	0.3	1.5	10	60	24	15	0	2
T-2	0.3	1.5	10	60	48	20	1	3
T-3	0.3	1.5	10	60	72	25	2	4
T-4	0.3	2	12	75	24	15	0	3
T-5	0.3	2	12	75	48	20	1	4
T-6	0.3	2	12	75	72	25	2	2
T-7	0.3	2.5	14	90	24	15	0	4
T-8	0.3	2.5	14	90	48	20	1	2
T-9	0.3	2.5	14	90	72	25	2	3
T-10	0.35	1.5	10	60	24	20	2	2
T-11	0.35	1.5	10	60	48	25	0	3
T-12	0.35	1.5	10	60	72	15	1	4
T-13	0.35	2	12	75	24	20	2	3
T-14	0.35	2	12	75	48	25	0	4
T-15	0.35	2	12	75	72	15	1	2
T-16	0.35	2.5	14	90	24	20	2	4
T-17	0.35	2.5	14	90	48	25	0	2
T-18	0.35	2.5	14	90	72	15	1	3
T-19	0.4	1.5	10	60	24	20	1	2
T-20	0.4	1.5	10	60	48	25	2	3
T-21	0.4	1.5	10	60	72	15	0	4
T-22	0.4	2	12	75	24	25	1	3
T-23	0.4	2	12	75	48	15	2	4
T-24	0.4	2	12	75	72	20	0	2
T-25	0.4	2.5	14	90	24	25	1	4
T-26	0.4	2.5	14	90	48	15	2	2
T-27	0.4	2.5	14	90	72	20	0	3

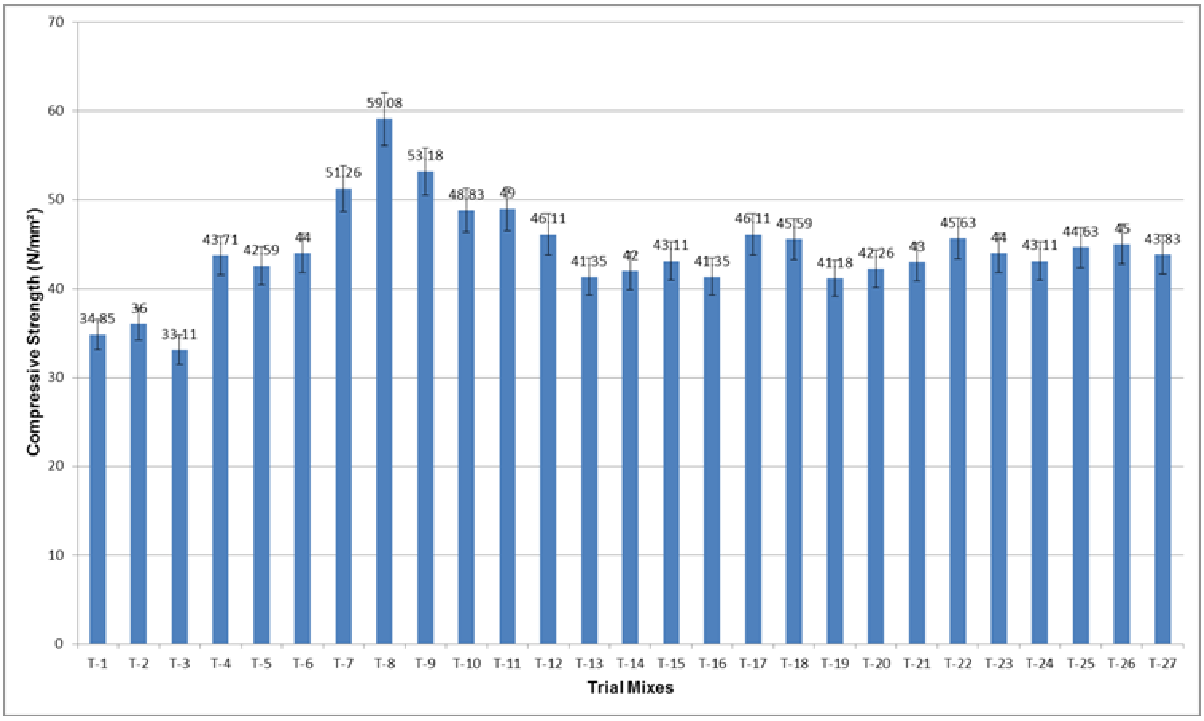

Fig.1 Compressive Strngth of Rubberized geopolymer concrete

Table- V: Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	6.497	6.497	3.249	1.14	0.358
B	2	184.218	184.218	92.109	32.33	0.000
C	2	136.827	136.827	68.414	24.02	0.000
D	2	334.713	334.713	167.356	58.75	0.000
E	2	11.171	11.171	5.586	1.96	0.191
F	2	0.717	0.717	0.358	0.13	0.883
G	2	6.725	6.725	3.362	1.18	0.347
H	2	17.595	17.595	8.797	3.09	0.090
Residual Error	10	28.488	28.488	2.849		
Total	26	726.950				

where, DF- degree of freedom, SS- sum of squares, P-percentage

Table- VI: ANOVA for each variable Larger is better.

Factors Levels	A	B	C	D	E	F	G	H
1	32.75	32.3	32.21	32.08	32.75	32.83	32.84	32.99
2	33.01	32.72	33.11	32.73	33.02	32.86	32.97	32.92
3	32.79	33.53	33.23	33.75	32.79	32.87	32.74	32.64
Delta	0.26	1.23	1.02	1.67	0.26	0.04	0.23	0.35
Rank	6	2	3	1	5	8	7	4

Table- VII: Optimal value for each factor that effects rubberized geopolymer concrete compressive strength

Factor	**Ratio of Alkaline to fly ash**	**Ratio of Na_2SiO_3/ NaOH**	**Concentration of NaOH**	**Cure temperature**	**Cure time**	**Water content (%)**	**Period of rest**	**Plasticizer (%)**
Optimum value	0.3	2.5	14M	90°C	48hr	20%	1 day	2%

VI. CONCLUSION

The research draws the following findings from experimental outcomes:

1) Curing temperature, NaOH concentration and sodium silicate to NaOH ratio are the most contributing factors in maximizing the compressive strength of rubberized geopolymer concrete. They were ranked as 1, 2 and 3 respectively from the ANOVA method. It was observed that an augment in values of these factors increase the compressive resistance of rubberized geopolymer concrete.
2) A rise in cure time after 48 hrs reduced the strength of rubberized concrete due to evaporation of water.
3) Maximum value for rubberized geopolymer concrete of the compressive force is obtained at ratio of alkaline solution to fly ash 0.35, Ratio of Sodium silicate to sodium hydroxide of 2.5, Concentration of NaOH 14M, cure temperature at 90°C, cure time 48hrs, water content 20%, rest period 1 day and superplasticizer 2%.

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AUTHORS PROFILE

Dr. Salmabanu Luhar, D.litt.(SAARC), D. Litt.(N. Korea), Postdoc. (Taiwan), Ph.D.eng, M.Eng, B.Eng, D.Eng, is an inventor, researcher, author, chartered engineer, approved valuer, and has worked for a research project funded by Department of Science and Technology (DST), Ministry of Science and Technology, New Delhi as Principal Investigator under “Woman Scientist” scheme. She has not only the experience as assistant professor but also well-known for her patent, European books, outstanding publications, national and global awards, records, and affiliations, etc. She has been bestowed with ‘Best researcher” award. Her research expertises are advances in conventional and geopolymer construction composites technology and construction building material science.

Dr. Ismail Luhar(GOLD MEDALIST), D.Litt.(N.Korea), M.Sc., B.Sc.; inventor, researcher, author. He is a topper in all subjects at his Masters, winning three academic gold medals. He is known to have a patent, to author books (Europe) and remarkable articles. He has been bestowed with “Best Research Paper Award, Dr. Vikram Sarabhai Life Time Achievement International Award”. His area of expertise is Geological structural engineering, Water resources, Geochemistry, Geopolymers and conventional Building materials technology. His research interests are structural, Petroleum, Environmental and Engineering Geology, Hydrogeology, Mineralogy, Gem Stones, Novel Construction Material science. material science.