# Construction of Key Mix Proportions of Concrete for Harsh Environments

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**ABSTRACT**

Making appropriate concrete which meet the durability requirements and performing in satisfactorily in coastal region is a grate task. In recent years, near costal line concrete structures are facing threads due to hash environments. Hence the construction industry has strongly raised the trust and recommends the high strength concrete that can minimize the deterioration and reduce the failure of concrete structures. This research investigation has focused to optimize the compressive strength of high strength concrete under harsh environmental conditions with respect to different mix parameters. In this study, the experiments were designed by a concept of design of experiments (DoE) along Taguchi method. Taguchi's standard orthogonal array (OA) of $L_9$ ($3^4$) was employed to obtained the working matrix with four mix parameters and three different levels. The parameters used were water-cement (w/c) ratio, cement content, fine aggregate content and coarse aggregate content. The samples were prepared according to matrix obtained by OA and cured in harsh environmental conditions like acidic and saline in nature. The obtained results were applied through Signal/Noise (S/N) ratio and ANOVA transformation. The results specified that the best level of mix parameters paid their own contribution for compressive strength for saline conditions. Optimum values of parameters were found out. The confirmation tests conducted based on the results, also indicated the same.

**KEY WORDS:** HSC, Taguchi method, Compressive strength, Mix proportions, harsh environments.

## 1. INTRODUCTION

Concrete is the widely accepted structural material to build verity of structures. This has been second most consumed material than water in the world. There is no alternate material for this in terms of its economy and durability. Now-a-days, concrete is used as construction material for hostile environment such as sea floors tunnels, off-shore piers and platforms, highway bridges, sewage pipes, and structures for solid and liquid wastes containing toxic chemicals and radioactive elements. When these concrete structures are exposed directly to harsh environments such as saline and acidic, it may cause harm to them. In order to avoid any disasters, engineers must take into account a harsh environment prior the mix design of concrete (Neville 1995). Generally the concrete structures were designed for a service life of 50 years, but experience shows that in urban and coastal environments begin to deteriorate many structures in 20 to 30 years or even less time of the life span. The trend towards designing concrete based on the environment can increase the service life of structures. Thus the environment impact on the structures can be reduced. Hence the construction industry hunts an alternative to reduce the impact of extreme harsh on concrete. Designing the mixture proportioning of high strength concrete is quite challenging one to achieve the required target strength as a vital hardened property to be considered. So, the optimization techniques are primarily required to improve possible combinations of material components, maximize the economic efficiency and the performance of concrete and reduce the variability among the construction material proportions. Designing the Concrete mixture proportioning involves the adaption of available resources to meet varying engineering demands, construction industry requirements, and economic needs. Optimization of concrete mix design is the procedure for fixing the best mixture constituents proportions to improve (minimize or maximize) the certain desirable properties of fresh or hardened concrete.

In the past many researchers use of optimization procedures to attain the best content of mix proportions to accomplish maximum strength for given set of materials and exposure conditions. The exiting literature shows that researchers have applied different techniques to optimize concrete mixes**.** A statistical approach of full factorial design methods (Simon, 1997; Li, 2013; Ahmed, 2016). Taguchi method has been extensively employed to optimize various limitations having single quality characterization that affect the performance of concrete mix (Turkmen, 2003; Hinislioglu, 2004; Ozbay, 2006; Tan, 2005; Chaulia and Das, 2008; Ozbay, 2009; Turkmen, 2009; Usyal, 2012; Rahim, 2012; Navaneethakrishnan, 2015). This approach is a fractional factorial optimizing technique which is successfully devised to design and high quality experimental procedures. It provides a systematic approach to optimize mix designs for performance quality. Taguchi parameter design can identify the influential process parameters to optimize the performance through setting of the design parameters and reduction of sensitivity system to source of variation.

**Need of this study:** In an engineering domain, an optimization plays an important role in designing of concrete mixes, and their process improvement. In the case of full factorial design, the number of experiments is numerous, and it is impossible to carry out all experiments practically. The fractional factorial experiments using an orthogonal array were investigated by Taguchi. Design of experiments (DoE) methods has been employed to identify the working parameters to improve the physical and mechanical properties of concrete as well as reduced the experimental burden and cut down the material requirement. This approach can substantially decrease the number of experiments and it is feasible to study the effect of factors and their interactions. The present study attempts to optimize the M55 grade of concrete mix constituents for harsh environmental conditions with limited number of mix trials.

## 2. EXPERIMENTAL PROGRAM

An investigational program was planned to find the optimum mix proportions of concrete for deliver better compressive strength after exposing the concrete specimens to harsh conditions such as normal, saline and acidic curing. The design of experiments of Taguchi method was deployed using $L_9(3^4)$ orthogonal array formulations with four parameters with three levels with a goal to attain maximum compressive strength using larger-the-better principle. By utilizing mix parameter design from Taguchi method, the experiments were conducted and the results were studied by analysis of variance (ANOVA) to find out the most contributing factors to the compressive strength of concrete

**Materials:** The materials used in the concrete mix were tested for its all physical properties. The cement used in preparing concrete mix was ordinary Portland cement (OPC) 53 grade in accordance with IS 8112:1989. The fine aggregates used in the mix (zone II) was locally available river sand in accordance with IS 383-1970. The specific gravity was found to be 2.65. In this experimental study nearby available coarse aggregates which also satisfy the criteria of IS 383-1970 of nominal size 20mm were used. Commercially existing super plasticizer was used as a chemical admixture.

**Fabrication of Mix Parameters:** In this experimental work, the design of experiments was involved to reduce the no of trials and Taguchi's methodology was employed to identify the main functional parameters and their levels. The main aim of the research is to improve the mechanical properties of the hardened concrete even after exposed to harsh environmental conditions. The selected parameters are cement content, fine aggregates and coarse aggregates content and water/cement ratio (w/c). In this research, the next step is to fix the appropriate levels for identified parameters. This was done based on the light of previous literatures and various researchers' attempts. In this work, Taguchi's standard orthogonal array (OA) of $L_9(3^4)$ was employed to obtained the experimental matrix with four mix parameters and three different levels. Table 1 shows the chosen three parameters and four levels. This standard $L_9(3^4)$ orthogonal array indicates which is having nine trial runs to accommodate all the effects of mix constituents. Table 2 shows orthogonal array (OA) with their combination of levels, code numbers for each levels and their absolute values. The 100mm cubic specimens were cast for cure in different curing conditions. Totally 180 cubes were cast. In addition 18 cubes more cubes were cast for conformation experiment. The Fig. 1 shows the cubes after casting.

**Fig.1. Shows the cubes after casting**

**Table.1. Chosen factors and its levels**

| Levels | Cement Content (P) kg/m$^3$ | Water-Cement ratio (Q) | Coarse aggregate content (R) kg/m$^3$ | Fine Aggregates content (S) kg/m$^3$ |
|---|---|---|---|---|
| 1 | 442 | 0.32 | 1163 | 649 |
| 2 | 463 | 0.30 | 1150 | 643 |
| 3 | 485 | 0.28 | 1136 | 636 |

**Curing regimes:** The specimens after 24 hours from casting were demoulded. Then the specimens were immersed in curing tanks for different curing conditions like normal water, saline water (NaCl) and acidic water (5% $H_2SO_4$).

**Testing:** After the 28 days and 56 days curing, the concrete specimens were taken out from curing tanks. The specimens were allowed to dry the surface then immediately moved to compressive testing. The compressive strength test was performed on cube specimens as per IS 516-1963. Table 3 shows the results of specimens. Fig. 2 indicates the samples progressive in testing.

**Table.2. $L_9$ ($3^4$) orthogonal array with trial mixes**

| Trial mix | Cement content (P) kg/m$^3$ | | Water to cement ratio (Q) kg/m$^3$ | | Coarse aggregates content (R) kg/m$^3$ | | Fine aggregates content (S) kg/m$^3$ | |
|---|---|---|---|---|---|---|---|---|
| | Level | Value | Level | Value | Level | Value | Level | Value |
| M-1 | 1 | 442 | 1 | 0.32 | 1 | 1163 | 1 | 649 |
| M-2 | 1 | 442 | 2 | 0.30 | 2 | 1150 | 2 | 643 |
| M-3 | 1 | 442 | 3 | 0.28 | 3 | 1136 | 3 | 636 |
| M-4 | 2 | 463 | 1 | 0.32 | 2 | 1150 | 3 | 636 |
| M-5 | 2 | 463 | 2 | 0.30 | 3 | 1136 | 1 | 649 |
| M-6 | 2 | 463 | 3 | 0.28 | 1 | 1163 | 2 | 643 |
| M-7 | 3 | 485 | 1 | 0.32 | 3 | 1136 | 2 | 643 |
| M-8 | 3 | 485 | 2 | 0.30 | 1 | 1163 | 3 | 636 |
| M-9 | 3 | 485 | 3 | 0.28 | 2 | 1150 | 1 | 649 |

**Fig.2. Samples under test**

**Table.3. Results of Compressive strength of concrete different curing conditions**

| Trial mixes | Normal curing (KN/mm$^2$) | | Saline curing (KN/mm$^2$) | | Acidic curing (KN/mm$^2$) | |
|---|---|---|---|---|---|---|
| | 28 days | 56 days | 28 days | 56 days | 28 days | 56 days |
| M-1 | 62.15 (100%) | 69.70 (100%) | 65.52 (105.42%) | 67.49 (108.59%) | 59.56 (95.83%) | 63.73 (102.54%) |
| M-2 | 63.23 (100%) | 64.43 (100%) | 66.58 (105.30%) | 68.68 (108.62%) | 62.98 (99.60%) | 60.54 (95.75%) |
| M-3 | 60.04 (100%) | 70.10 (100%) | 63.40 (105.60%) | 71.77 (119.54%) | 58.67 (97.72%) | 62.78 (104.56%) |
| M-4 | 69.33 (100%) | 71.69 (100%) | 72.92 (105.18%) | 72.36 (104.37%) | 66.67 (96.16%) | 68.62 (98.98%) |
| M-5 | 59.68 (100%) | 64.50 (100%) | 62.35 (104.47%) | 73.22 (122.69%) | 58.33 (97.74%) | 62.41 (104.57%) |
| M-6 | 61.80 (100%) | 63.80 (100%) | 64.46 (104.30%) | 66.39 (107.43%) | 59.54 (96.34%) | 61.54 (99.58%) |
| M-7 | 66.24 (100%) | 69.28(100%) | 70.12 (105.86%) | 71.52 (107.97%) | 65.58 (99.00%) | 66.88 (100.97%) |
| M-8 | 66.10 (100%) | 69.02 (100%) | 69.74 (105.51%) | 70.13 (106.10%) | 62.00 (93.80%) | 67.34 (101.88%) |
| M-9 | 67.50 (100%) | 68.53 (100%) | 70.80 ((104.89%) | 70.54 (104.50%) | 66.83 (99.01%) | 63.15 (93.56%) |

**Analysis of results:** The initial step of Taguchi method is to identify the performance characteristics. There are mainly three categories of performance characteristics, nominal the better, larger the better and smaller the better (Turkmen). The main goal of this paper is to get optimum concrete mix proportion to obtain best compressive strength under the extreme conditions. So 'larger the better' type performance characteristic was chosen and corresponding S/N ratio was calculated using the equation below:

$$\frac{S}{N} = -10 * Log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \qquad (1)$$

Where Yi is the i$^{th}$ experiment's values, S/N are performance statistics (S/N unit: dB) and $Y_i$ is the nominal value desired. In this method, the trials conforming to the optimum mix may or may not have been executed during the trials. In such cases the compressive strength conforming to the optimum conditions can be predicted by using the following equation:

$$Yi = \mu + Xi + e_i \qquad (2)$$

Where Xi the stable effect of parameter level combination used in i$^{th}$ trial, μ is the total mean of the value and e is the random error in the test.

Since equation (1) is a point approximation calculated by using experimental records in order to determine whether results of confirmation experiments are significant or not, the confidence interval must be calculated. The confidence interval is calculated by using the following equation:

$$CI = \mu \pm \sqrt{\frac{F(1,n2)v_e}{Ne}} \qquad (3)$$

Where Ne is the effective number of repetitions; F(1, n2), F is obtained from F table from statistical book corresponding to essential confidence level and at degree of freedom 1 and error degree of freedom $n_2$; $V_e$, the change of error term (ANOVA); and μ is the total performance value at the optimum situations. The test results were analyzed to determine the influence of factors. The average compressive strength and signal to noise ratio of various mix combinations were measured and used for evaluating the results. The approach was followed in the present study to choose the mix combinations which attains the target strength of M55 grade. The Table 4 is showing analyzed responses of signal to noise ratio data for given combination of mix parameters. This was followed in each case i.e., for normal, saline and acidic curing. It has been observed that the parameters have changed the effect on the compressive strength with variation in the curing environment. Irrespective of the mix, the compressive strength was found to slightly higher than under normal condition. From Table 3, the 56 days compressive strength of normal curing samples compared with 28 days, among all mixes the mix (M3) obtained 16% higher strength with corresponding mix. This may be due to crystallization of salts in the voids in concrete and also due to rate of gaining strength in normal condition is lesser than that of the saline condition (Wegian, 2010). In this case the, for 28 days results, cement content is the most influencing parameter followed by coarse aggregates content. The influencing parameters are fine aggregates and water to cement ratio. It has been observed from Table 4, that maximum S/N ratio for 28 days is given by the level 3 (485 kg/m$^3$) for factor P, level 1(0.32) for factor Q, level 2 (1150 kg/m$^3$) for factor R and level 3 (636 kg/m$^3$) for factor S whereas for 56 days the maximum S/N ratio was given by level 3 (485 kg/m$^3$) for factor P, level 2 (0.30) for factor Q, level 3 (1136kg/m$^3$) for factor R and level 3 (636 kg/m$^3$) for factor S.

The cubes cured in acidic curing of the 5% $H_2SO_4$, the compressive strength results form Table 3 was found to be less compared to the compressive strength of other two curing conditions. The cubes have cured for 56 days reveals escalated the deterioration. This may be due to the neutralization of $H_2SO_4$ with $Ca(OH)_2$ present in the concrete (Araghi, 2015). According to the results, the maximum S/N ratio at 28 days is shown by level 3 (485 kg/m$^3$) by factor P, level 1 (0.32) by factor Q, level 2 (1150 kg/m$^3$) by factor R and level 2 (643 kg/m$^3$) by factor S whereas for 56 days the maximum S/N ratio was given by level 3 (485 kg/m$^3$) for factor P, level 1 (0.32) for factor Q, level 1 (1163kg/m$^3$) for factor R and level 3 (636 kg/m$^3$) for factor S.

A statistical analysis was also conducted for assesses the impact of each factor with its influence on the optimization of compressive strength of concrete under various harsh environments. The results from the analysis of variance revealed that when the concretes cubes were cured in normal curing for 28 days, parameters cement and coarse aggregates contributed more to the compressive strength. They contributed about 31.614% and 30.847% respectively after pooling. W/C ratio and fine aggregates doesn't have much impact on the strength. In the case of 56 days results fine aggregates and water to cement ratio had a maximum contribution of 43.656% And 40.207% contribution.

In case of specimens cured in NaCl solution, cement (29.332%) and fine aggregates (25.756%) showed the maximum contribution for 28days. Water cement ratio and coarse aggregates showed slightly less contribution of 19.778% and 16.756%. Results from specimens cured for 56 days revealed that coarse aggregates contributed the most with 55.490%. The cement, water cement ratio and fine aggregates contributed about 15.843%, 11.887% and 16.779% respectively.

For the specimen cured in acidic solutions coarse aggregates and cement showed the maximum contribution with 47.818% and 30.756% respectively for 28 days. W/C ratio contributed about 11% of compressive strength. Fine aggregates showed the least contribution (4%). Results from specimens cured for 56 days revealed that cement (28.251%), W/C ratio (39.424%) and fine aggregates (32%) contribution.

**Table.4. Analyzed results of signal to noise (S/N) ratio for harsh environments**

| Level | Cement (A) | Water to cement ratio (B) | Coarse aggregates(C) | Fine aggregates(D) |
|---|---|---|---|---|
| Normal curing -28 days | | | | |
| 1 | 35.819 | 36.370 | 36.031 | 35.990 |
| 2 | 36.052 | 35.980 | 36.474 | 36.087 |
| 3 | 36.471 | 35.992 | 35.836 | 36.264 |
| Normal curing -56 days | | | | |
| 1 | 36.654 | 36.929 | 36.580 | 36.591 |
| 2 | 36.465 | 36.384 | 36.669 | 36.363 |
| 3 | 36.770 | 36.576 | 36.639 | 36.934 |
| Saline curing -28 days | | | | |
| 1 | 36.279 | 36.834 | 36.461 | 36.408 |
| 2 | 36.446 | 36.411 | 36.908 | 36.523 |
| 3 | 36.929 | 36.409 | 36.285 | 36.723 |
| Saline curing -56 days | | | | |
| 1 | 36.813 | 36.954 | 36.648 | 36.949 |

| | | | | |
|---|---|---|---|---|
| 2 | 36.975 | 36.983 | 36.965 | 36.756 |
| 3 | 36.992 | 36.843 | 37.167 | 37.076 |
| Acidic curing -28 days | | | | |
| 1 | 35.617 | 36.104 | 35.614 | 35.772 |
| 2 | 35.764 | 35.716 | 36.320 | 35.938 |
| 3 | 36.227 | 35.788 | 35.674 | 35.898 |
| Acidic curing -56 days | | | | |
| 1 | 35.895 | 36.440 | 36.145 | 36.000 |
| 2 | 36.139 | 36.037 | 36.126 | 35.977 |
| 3 | 36.360 | 35.916 | 36.122 | 36.417 |

**Effect of Cement content:** The effects of cement content on cube compressive strength for each case are shown in Table 5. From the test results, it can be seen that in each case as cement content increases, the S/N ratio also increases. Hence compressive strength improves with increase in cement content. It can also be seen that optimum mix obtained for various conditions have the same cement content.

**Table.5. Confirmation results for 28 days and 56 days**

| Curing Environment | Cement content ($Kg/m^3$) | Water to cement ratio | Coarse aggregates content ($Kg/m^3$) | Fine aggregates content ($Kg/m^3$) | Compressive strength ($KN/mm^2$) |
|---|---|---|---|---|---|
| **28 days** | | | | | |
| Normal | 485 | 0.32 | 1150 | 636 | **69.18** |
| Saline | 485 | 0.32 | 1150 | 636 | **71.98** |
| Acidic | 485 | 0.32 | 1150 | 643 | **67.53** |
| **56 days** | | | | | |
| Normal | 485 | 0.32 | 1150 | 636 | **71.87** |
| Saline | 485 | 0.30 | 1136 | 636 | **73.15** |
| Acidic | 485 | 0.32 | 1163 | 636 | **68.45** |

**Effect of Water/ Cement ratio:** From the test results, it can be seen that in each case the increased W/C ratio performed well than lower W/C ratio, therefore the S/N ratio also increases. Hence compressive strength improves with increase in water to cement ratio. It can also be seen that optimum mix obtained for various conditions have mostly 0.32 as their water to cement ratio.

**Effect of Coarse aggregates:** The effects of coarse aggregates on cube compressive strength for each case are shown in Figure 6.1 to 6.6. From the test results, it can be seen that there is no particular pattern for coarse aggregates content. But it can also be seen that optimum mix obtained for various conditions for 28 days have mostly 1150 $kg/m^3$ as their coarse aggregates content.

**Effect of fine aggregates:** The effects of fine aggregates content on cube compressive strength for each case are shown in Figure 6.1 to 6.6. From the test results, it can be seen that in each case (except for acidic) as fine aggregates decreases, the S/N ratio also increases. Hence compressive strength improves with decrease in fine aggregates. It can also be seen that optimum mix obtained for various conditions have mostly 636 as their fine aggregates content

**Confirmation Experiments:** In order to test the predicted results, confirmation experiments were conducted based on the data obtained from Table 4. It is observed that almost all results are within the calculated confidence interval of 95%. The calculated values of various response averages are shown in Table 5 for different harsh environments.

## 4. CONCLUSION

An investigational study was done to optimize the factors of mix proportions of high strength concrete in order to capitalize on the compressive strength of concrete under harsh environments. The optimization process was recognized by Taguchi approach by conducting the experiments using $L_9(3^4)$ orthogonal array with four factors and three levels of each factor. From the results, the following deductions can be arrived:

- This research founds the optimum mix proportions for concrete under harsh environments for 28 and 56 days to attain the maximum compressive strength. Optimum conditions at normal water curing condition exposure for 28 and 56 days are found to be 485 $kg/m^3$ cement content, 0.32 water-cement ratio, 636 $kg/m^3$ fine aggregates and 1150$kg/m^3$ coarse aggregates.
- The optimum mix parameters for concrete exposed to saline curing condition are determined as 485 $kg/m^3$ cement content, 0.32 water-cement ratio, 636 $kg/m^3$ fine aggregates and 1150$kg/m^3$ coarse aggregates for 28 days. In case of 56 days the optimum mix parameters were found as 485 $kg/m^3$ cement content, 0.3 water-cement ratio, 636 $kg/m^3$ fine aggregates and 1163$kg/m^3$ coarse aggregate.
- The optimum mix parameters at acidic curing environment are found to be 485 $kg/m^3$ cement content, 0.32 water-cement ratio, 643 $kg/m^3$ fine aggregates and 1150$kg/m^3$ coarse aggregates whereas for 56 days it was 485 $kg/m^3$ cement content, 0.32 water-cement ratio, 636 $kg/m^3$ fine aggregates and 1163$kg/m^3$ coarse aggregate

- The test results for 28 days indicated that the overall most influencing parameter is cement content followed by coarse aggregates content ratio, water cement ratio and fine aggregates content. This information be useful and can considered while designing a mix for saline and acidic environment.

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