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# The taguchi optimization of mechanical and durability properties of accelerator added concrete

# *Priz hızlandırıcı katkılı betonun mekanik ve dayanıklılık özelliklerinin taguchi optimizasyonu*

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# The Taguchi Optimization of Mechanical and Durability Properties of Accelerator Added Concrete

***Highlights***

- *Effect of the accelerator on fresh and hardened concrete properties*
- *If the amount of accelerator exceeds 1%, it has a negative effect on compressive strength.*
- *Obtaining the optimum mixture design with Taguchi optimization.*

***Graphical Abstract***

*In this study, it is aimed to produce a concrete mixture with high initial strength and workability by using an accelerator.*

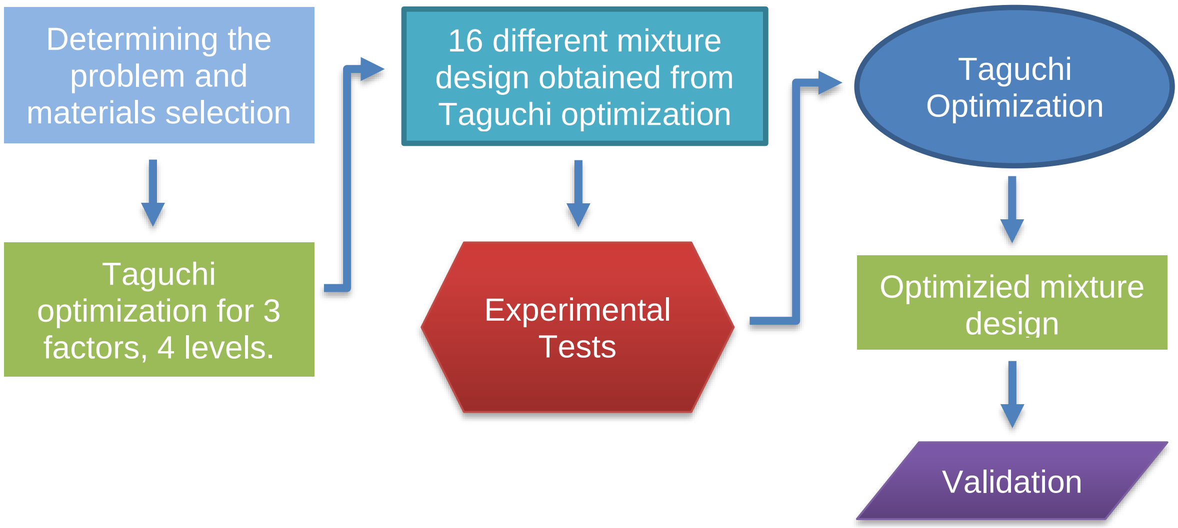


**Figure.** The graphical abstract of the study


***Aim***

*In this study, it is aimed to produce a concrete mixture with high initial strength and workability using an accelerator.*

***Design & Methodology***

*The mixture with W/C ratio, cement, and accelerator at 4 different levels have been optimized by the Taguchi method.*

***Originality***

*An optimum mixture with the aimed properties has been achieved.*

***Findings***

*If the amount of accelerator exceeds 1%, it has a negative effect on compressive strength.*

***Conclusion***

*A mixture that provides rapid setting and high workability has been obtained. It has been determined that this mixture can be used especially in the prefabricated industry where rapid production is important.*


***Declaration of Ethical Standards***

*The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.*

# The Taguchi Optimization of Mechanical and Durability Properties of Accelerator Added Concrete

***Araştırma Makalesi / Research Article***

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**ABSTRACT**

It is very important to save time during the assembly of prefabricated elements. In wet connection types, the setting time of the concrete might lead time lose. There are many studies investigates the methods to shorten the setting time of concrete. Especially in the recent years, there are accelerators developed to shorten concrete setting time without causing corrosion. However, the negative effect of accelerators on fresh concrete properties such as workability makes them difficult to use. In this study, it is aimed to produce a concrete mixture with high initial strength and workability by using an accelerator. However, it is highly difficult to determine proper ratio of the accelerator for the mixture without precasting significant number of concrete samples which requires time, manpower and material consumption. Therefore, Taguchi optimization is very useful method in order to reduce this number of samples and effort. The optimum mixture has been achieved by performing the required tests applied to mixture designs obtained from Taguchi optimization.

**Keywords: Taguchi methods, accelerators, prediction of compressive strength.**

# Priz Hızlandırıcı Katkılı Betonun Mekanik ve Dayanıklılık Özelliklerinin Taguchi Optimizasyonu

**ÖZ**

Prefabrike elemanların montajı sırasında zamandan tasarruf etmek çok önemlidir. Islak bağlantı türlerinde betonun priz alma süresi zamandan tasarruf edilmesini engellemektedir. Betonun priz süresini kısaltmak için literatürde birçok çalışma vardır. Özellikle son yıllarda korozyona neden olmadan beton priz süresini kısaltmak için geliştirilmiş priz hızlandırıcılar bulunmaktadır. Ancak priz hızlandırıcıların işlenebilirlik gibi taze beton özellikleri üzerindeki olumsuz etkisi, kullanımını zorlaştırmaktadır. Bu çalışmada, priz hızlandırıcı kullanılarak başlangıç dayanımı ve işlenebilirliği yüksek bir beton karışımı amaçlanmıştır. Bununla birlikte, kullanılacak priz hızlandırıcı oranını belirlemek için çok fazla karışım ortaya çıkmaktadır. Bu nedenle, Taguchi optimizasyonu ile karışım sayıları azaltılmıştır. Taguchi optimizasyonundan elde edilen karışım tasarımlarına gerekli testler yapılarak optimum karışım elde edilmiştir.

**Anahtar Kelimeler: Taguchi yöntemi, priz hızlandırıcılar, basınç dayanımı tahmini.**

## 1. INTRODUCTION

Precast concrete structures are preferred all over the world due to their fast production and low cost [1]. Prefabricated construction systems enable high-quality structures to be produced cheaply and in a short time [2]. Prefabricated construction elements are manufactured in the factory and assembled on the construction site [3]. Wet connection types are used during assembly at the construction site slow down the installation rate. Therefore, the type of concrete that gains early strength is extremely important for the prefabricated industry. There are many studies on early strength gain of concrete [4–7]. The early-strength concrete should be able to meet the minimum requirements of concrete in terms of mechanical and durability. Hardened concrete properties such as compressive strength, flexural strength, the permeability of connection concrete between precast construction elements are substantial during their service life. However, most early-strength concrete mixtures are not applicable for precast industry [8]. The early-strength concrete mixtures have some disadvantages namely; very short setting time, low workability, using expensive composite materials [8]. Therefore, a low-cost and applicable concrete mixture for the prefabricated industry is sought. Some chemicals have been used as accelerators in the recent years. Especially, inorganic salts containing ions with lower activity such as $Ca(NO_2)_2$, $Ca(NO_3)_2$ are used as accelerators [6,7]. However, for these chemicals to be used, appropriate mixing ratios must be obtained by experiment. Furthermore, the most significant problem in deciding the proper ratio is that high number of concrete mixtures should be casted in the labrotaory. The evaluations to obtain the optimum mixture are an important area for engineering [9]. The researchers seek ways to avoid the time and cost required by the laboratory testing process [10,11]. The results are obtained by trial and error in the traditional mixture

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design. Traditional mixture predictions or designs are made by linear or nonlinear regression equations based on statistical analysis. Hence, traditional mixture prediction or design methods are very difficult tasks [12]. Besides, the nonlinear relationships obtained with these equations may give inaccurate results [13,14]. Therefore, it is increasingly common to optimize the mixture using computational optimization methods. There are many different optimization methods such as Taguchi [15–17] and machine learning [18–22] methods. The Taguchi optimization method is one of the most preferred optimization methods to optimize experimental parameters because it is used both in analysis and optimization [23,24]. The Taguchi optimization method is a method preferred to design parameters with a minimum number of tests and samples [25]. Besides, the combination of optimum parameters can be obtained after analysis using the Taguchi method [26]. There are many studies about design and estimation with the Taguchi method in different research fields. Celik et al. conducted the Taguchi optimization method on the factor levels of turbulated heat exchangers [27]. Teimortashlu et al. applied the Taguchi optimization method for compressive strength optimization of tertiary blended self-compacting mortar. 3 different factors as flay ash, slag, and nano $SiO_2$ were used as input. Optimum mixing ratio at 4 different levels for 3 factors was obtained by the Taguchi optimization method [28]. Chen ve Kurniawan used the Taguchi method to optimize process parameters for different quality attributes in plastic infusion shaping. Melting heat, infusion velocity, pressure packing, packing time, and cooling time are defined as control factors [29]. Gopalsamy et al. conducted the Taguchi optimization method for process parameters optimization of hard machining while machining strengthened steel. Taguchi $L_{18}$ orthogonal array was employed. Shear velocity, advance, depth of shear, and width of width were selected as control factors [30]. Mehta et al. investigated the effect of several parameters on strength and suction properties of fly ash-based geopolymer concrete planned by the Taguchi optimization method. The Taguchi $L_{16}$ orthogonal array was employed. Fly ash replacement by ordinary Portland cement, NaOH molarity, and curing heat were determined as control factors. Control factors were applied for four different levels [31]. Jafari et al. optimized the mixture design of polymer concrete. Polymer content, temperature, and aggregate size were selected as control factors. Control factors were determined for three different levels. The mixture design with a polymer content of 14%, containing coarse aggregates ranging size between 9.5 and 19 mm, and tested under a temperature exposure of -15 ºC was obtained as optimum design in terms of compressive, flexural, and splitting-tensile strengths [32].

The purpose of this study is to obtain concrete that sets rapidly and has high workability with little loss of strength. Therefore, 3 factors are used as inputs. 4 different levels are determined by changing the cement, water/cement (w/c), and accelerator ratios. Optimum values are obtained for the compressive and spread diameter of the mixture.Precast concrete structures are preferred all over the world due to their fast production and low cost [1]. Prefabricated construction systems enable high-quality structures to be produced cheaply and in a short time [2]. Prefabricated construction elements are manufactured in the factory and assembled on the construction site [3]. Wet connection types are used during assembly at the construction site slow down the installation rate. Therefore, the type of concrete that gains early strength is extremely important for the prefabricated industry. There are many studies on early strength gain of concrete [4–7]. The early-strength concrete should be able to meet the minimum requirements of concrete in terms of mechanical and durability. Hardened concrete properties such as compressive strength, flexural strength, the permeability of connection concrete between precast construction elements are substantial during their service life. However, most early-strength concrete mixtures are not applicable for precast industry [8]. The early-strength concrete mixtures have some disadvantages namely; very short setting time, low workability, using expensive composite materials [8]. Therefore, a low-cost and applicable concrete mixture for the prefabricated industry is sought. Some chemicals have been used as accelerators in the recent years. Especially, inorganic salts containing ions with lower activity such as $Ca(NO_2)_2$, $Ca(NO_3)_2$ are used as accelerators [6,7]. However, for these chemicals to be used, appropriate mixing ratios must be obtained by experiment. Furthermore, the most significant problem in deciding the proper ratio is that high number of concrete mixtures should be casted in the labrotaory. The evaluations to obtain the optimum mixture are an important area for engineering [9]. The researchers seek ways to avoid the time and cost required by the laboratory testing process [10,11]. The results are obtained by trial and error in the traditional mixture design. Traditional mixture predictions or designs are made by linear or nonlinear regression equations based on statistical analysis. Hence, traditional mixture prediction or design methods are very difficult tasks [12]. Besides, the nonlinear relationships obtained with these equations may give inaccurate results [13,14]. Therefore, it is increasingly common to optimize the mixture using computational optimization methods. There are many different optimization methods such as Taguchi [15–17] and machine learning [18–22] methods. The Taguchi optimization method is one of the most preferred optimization methods to optimize experimental parameters because it is used both in analysis and optimization [23,24]. The Taguchi optimization method is a method preferred to design parameters with a minimum number of tests and samples [25]. Besides, the combination of optimum parameters can be obtained after analysis using the Taguchi method [26]. There are many studies about design and estimation with the Taguchi method in different research fields. Celik et al.

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The purpose of this study is to obtain concrete that sets rapidly and has high workability with little loss of strength. Therefore, 3 factors are used as inputs. 4 different levels are determined by changing the cement, water/cement (w/c), and accelerator ratios. Optimum values are obtained for the compressive and spread diameter of the mixture.

## 2. EXPERIMENTAL and OPTIMIZATION PROGRAM

The number of mixtures to be carried out is determined to be 16 which is required by $L_{16}$ Taguchi Orthogonal Array optimization method. Fresh and hardened properties of the mixtures are performed for 16 designs. Taguchi optimization method is conducted to the experimental results of 16 designs to obtained optimization mixture ratios.

### 2.1. Materials, Mixtures, and Test Program

In this study, standard CEM II 42.5 portland cement is utilized. The density of the cement is 3200 kg/m$^3$. The chemical and physical features of cement are given in Table 1.

**Table 1.** Chemical and physical features of cement

| Properties | Values | Unit |
|---|---|---|
| CaO | 54-62 | % |
| $Al_2O_3$ | 3.5-5.7 | % |
| $SO_3$ | 2.2-3.5 | % |
| Cl | 0-0.17 | % |
| MgO | 0.8-2.3 | % |
| $Na_2O$ | 0.2-0.7 | % |
| $SiO_2$ | 20-26 | % |
| $Fe_2O_3$ | 2.1-3.7 | % |
| $K_2O$ | 0.2-0.8 | % |
| Initial setting-time | 168 | Min. |
| Final setting-time | 199 | Min. |
| Bulk density | 875 | g/l |
| 2 days strength | 27.6 | MPa |
| 28 days strength | 59.8 | MPa |

Silica sand is utilized as fine aggregate. The density of silica sand is 2540 kg/m$^3$. The chemical composition of silica sand is given in Table 2. The particle size distribution of silica sand is given in Figure 1.

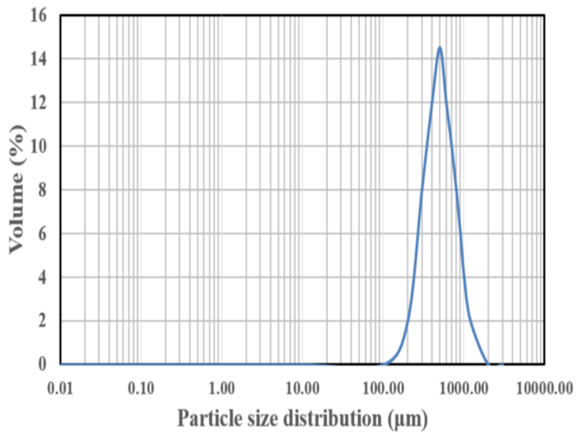


**Figure 1.** The particle size distribution of silica sand

**Table 2.** The chemical composition of silica sand

| **Chemical composition** | **(%)** |
|---|---|
| $SiO_2$ | 92.5 |
| $TiO_2$ | 0.087 |
| CaO | 2.16 |
| $Al_2O_3$ | 1.63 |
| $SO_3$ | 0.0228 |
| $Cr_2O_3$ | 0.178 |
| MgO | 0.145 |
| $ZnO_2$ | 0.0176 |
| BaO | 0.00548 |
| $Fe_2O_3$ | 1.65 |
| $K_2O$ | 0.348 |
| $Na_2O$ | 0.027 |

Polycarboxylic ether-based accelerator is used. The technical features of the accelerator are given in Table 3.

**Table 3.** Technical features of accelerator

| **Technical properties of the accelerator** | **Value** |
|---|---|
| Material structure | Polycarboxylic ether-based |
| Colour | Light Brown |
| Density | 1.13±0.05 kg/l |
| Melting point | - |
| Burning point | - |
| pH value | - |
| Chlorine content % | <0.1 |
| Alkali content % | <3 |

The technical properties of the hyperplasticizer are presented in Table 4.

**Table 4.** Technical features of hyper plasticizer

| **Technical properties of hyperplasticizer** | **Value** |
|---|---|
| Colour | Milky brown |
| Boiling point | 95-105 $^oC$ |
| Thermal decomposition | > 720 $^oC$ |
| Density | 1.25 $g/cm^3$ |
| Ph value | 9.2-12.0 |
| Water solubility | Water-soluble |

In this study, Taguchi optimization is carried out as 3 factors (cement, w/c, and accelerator) and 4 levels. 16 mixture designs are prepared according to Taguchi optimization. All mixture designs are given in Table 5. The concrete production process is given in Figure 2.

**Figure 2.** The concrete production process

The flow table test was conducted according to TS-EN12350-5 [33]. Cement paste was placed in a mold in two layers. Then the spread diameter was measured by dropping the table 15 times. Nine samples were taken from each mixture at 1 day, 7 days, and 28 days compressive strength test. The test samples were taken into the curing pools at 20 $^0C$ [34]. The compressive strength tests were conducted on the 150x150x150 mm cubic specimens according to TS 3114 [35]. The compressive strength tests were performed for 1 day and 28 days. The compressive strength tests are given in Figure 3.


**Figure 3.** The compressive strength tests

**Table 5.** Mixture designs (per 0.6 $m^3$)

| Mixture Design | Silica Sand (kg) | Cement (kg) | W/C | Accelerator (% by wt. of cement) | Hyperplasticizer (% by wt. of cement) |
|---|---|---|---|---|---|
| $S_0$ | 500 | 470 | 0.30 | 0 | 0.50 |
| $S_1$ | 500 | 470 | 0.30 | 0.50 | 0.50 |
| $S_2$ | 500 | 470 | 0.32 | 0.75 | 0.50 |
| $S_3$ | 500 | 470 | 0.34 | 1.00 | 0.50 |
| $S_4$ | 500 | 470 | 0.36 | 1.25 | 0.50 |
| $S_5$ | 500 | 480 | 0.30 | 0.75 | 0.50 |
| $S_6$ | 500 | 480 | 0.32 | 0.50 | 0.50 |
| $S_7$ | 500 | 480 | 0.34 | 1.25 | 0.50 |
| $S_8$ | 500 | 480 | 0.36 | 1.00 | 0.50 |
| $S_9$ | 500 | 490 | 0.30 | 1.00 | 0.50 |
| $S_{10}$ | 500 | 490 | 0.32 | 1.25 | 0.50 |
| $S_{11}$ | 500 | 490 | 0.34 | 0.50 | 0.50 |
| $S_{12}$ | 500 | 490 | 0.36 | 0.75 | 0.50 |
| $S_{13}$ | 500 | 500 | 0.30 | 1.25 | 0.50 |
| $S_{14}$ | 500 | 500 | 0.32 | 1.00 | 0.50 |
| $S_{15}$ | 500 | 500 | 0.34 | 0.75 | 0.50 |
| $S_{16}$ | 500 | 500 | 0.36 | 0.50 | 0.50 |

### 2.2. Optimization Program

The Taguchi optimization method is a powerful method for optimizing a product. Taguchi optimization minimizes signal-to-noise (S/N) factors. S/N ratios are conducted as 'Larger is better' for the strength and spread diameters. The Taguchi optimization was used to obtain optimum mixture to maximize workability and minimize the setting time during saving compressive strength. Each control factor and level for optimization are given in Table 6.

**Table 6.** Control factors and levels

| Control Factors | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| Cement (kg) | 470 | 480 | 490 | 500 |
| W/C | 0.30 | 0.32 | 0.34 | 0.36 |
| Accelerator (%by wt. of | 0.50 | 0.75 | 1.00 | 1.25 |

## 3. RESULTS and DISCUSSION

### 3.1. Experimental Test Results

Spread diameter test results are given in Figure 4. An increase in the W/C ratio has a positive impact on spread diameter test. Increasing cement decreases the spread diameter due to the need of water incrases to obtain the same W/C ratio. As the accelerator accelerates the hydration reactions which results in formation of C-S-H gel and ettrringite , the increase of the accelerator decrease the spread diameter. [36]. During the formation of C-S-H gel and ettringite, the mixture loses its plasticity rapidly. The reason for this is that increasing the amount of accelerator decreases the nucleation of hydration products and thus increases the cement hydration rate [37]. The highest spread diameter was determined to be 193 mm in the mixture design that has 490 kg cement, 0.36 W/C ratio, and 0.75% accelerator by weight of cement.

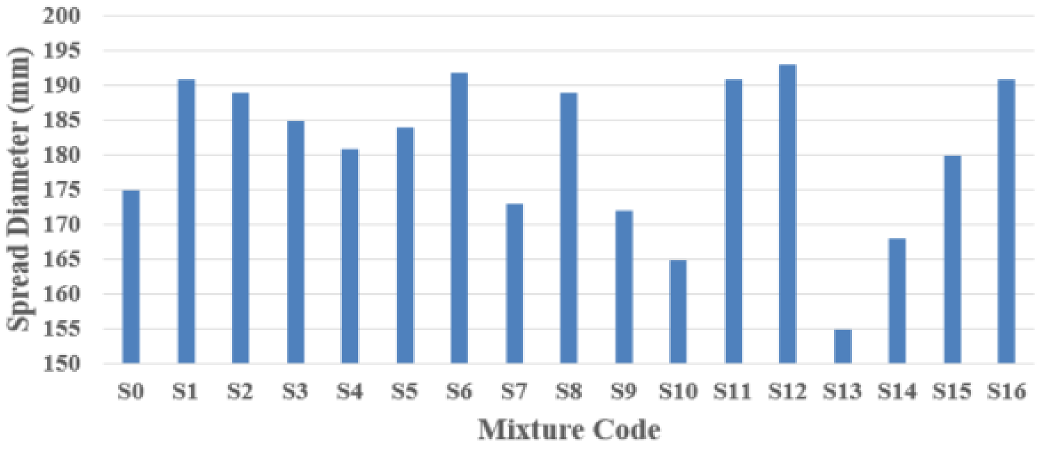


**Figure 4.** Spread diameter of mixture design samples

Compressive strength test results for 1 day, 7 days, and 28 days are given in Figure 5. As it can be seen from Figure 5, the accelerator increases the compressive strength due to its contribution to the occurrence of C-S-H[38,39]. In the medium and long term, its compressive strength decreases compared to the mixture without an accelerator. The main reason for this is that the volume of C-S-H that produced at the normal chemical reaction (the concrete without accelerator) is greater than the C-S-H volume produced in the chemical reactions in which accelerator used.. The decrease in the volume of C-S-H negatively affects the compressive strength. The highest compressive strength for 28 days was obtained to be 48.21 MPa in the mixture design that has 500 kg cement, 0.30 W/C ratio, and 1.25% accelerator by weight of cement.

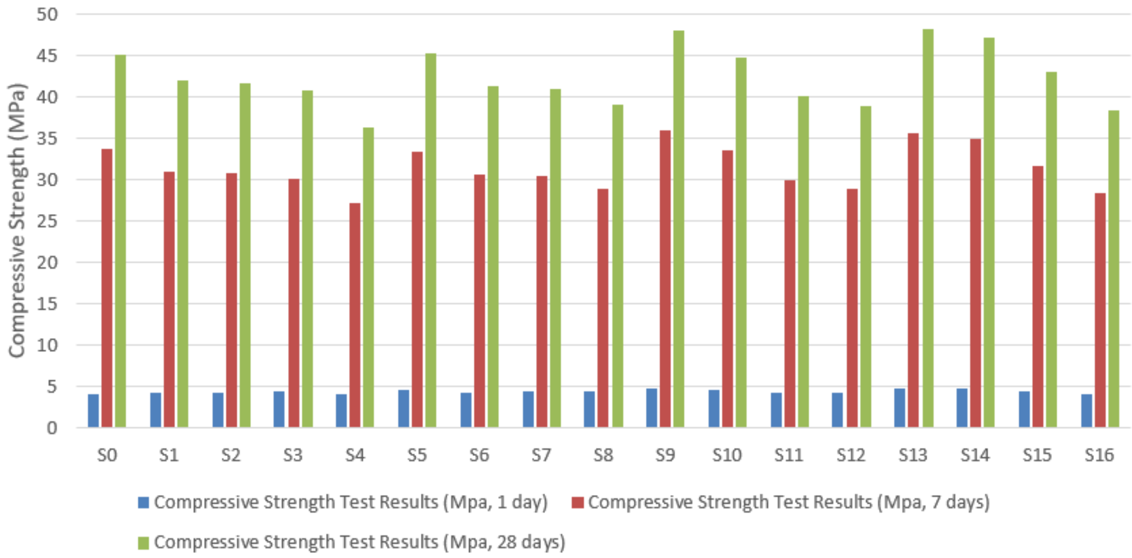


**Figure 5.** Compressive strength of mixture design samples

### 3.2. Optimization Results

Spread diameter optimization results based on the Taguchi method are shown in Figure 6. The highest spread diameter according to design results was obtained as 470 kg cement, 0.36 W/C ratio, and 0.50% by weight of cement contents. As the W/C ratio increases, the workability of fresh concrete increases. While excess water in hydration increases workability, it will cause voids in the concrete as a result of the evaporation of excess water in the medium and long term. Therefore, it causes compressive strength to decrease. The spread diameter optimization results changed from 155 mm to 193 mm with changing cement, W/C ratio, accelerator dosage. These results are consistent with the literature results [36].

Compressive strength optimization results at 1 day and 28 days are given in Figure 7 and Figure 8, respectively. Maximum compressive strength is obtained as 500 kg cement, 0.30 W/C ratio, and 1.00% accelerator dosage for 1 day and 28 days. The compressive strength for 28 days optimization results increased from 36.42 MPa to 48.21 MPa. These results are consistent with the literature results [38,39]. Optimization results for the Taguchi optimization method are plotted in Figure 9. Optimization results for the Taguchi optimization method are plotted in Figure 9.

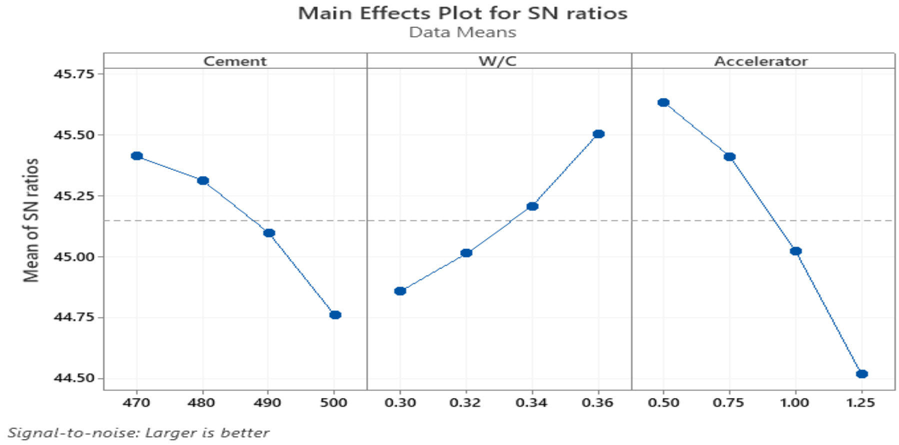


**Figure 6.** Spread diameter optimization results

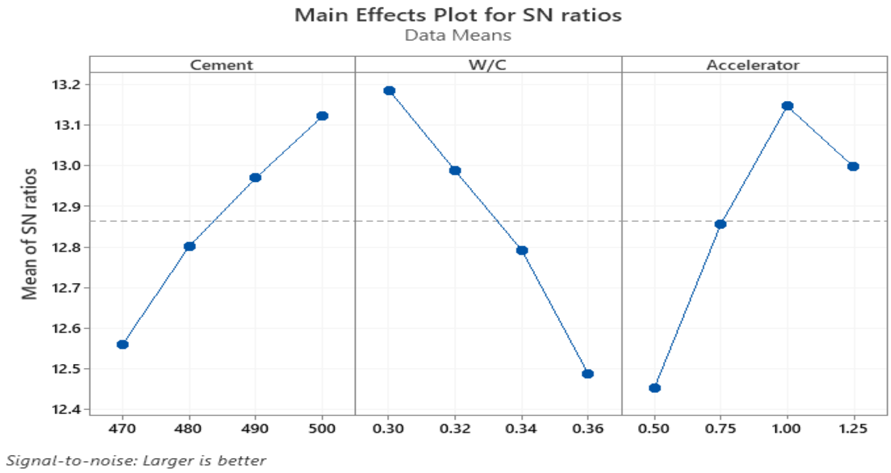


**Figure 7.** Compressive strength for 1-day optimization results

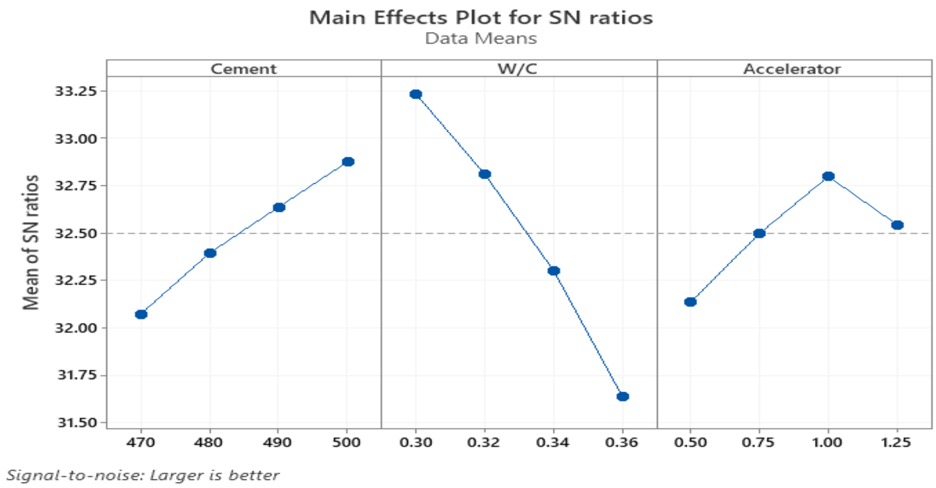


**Figure 8.** Compressive strength for 28 days optimization results

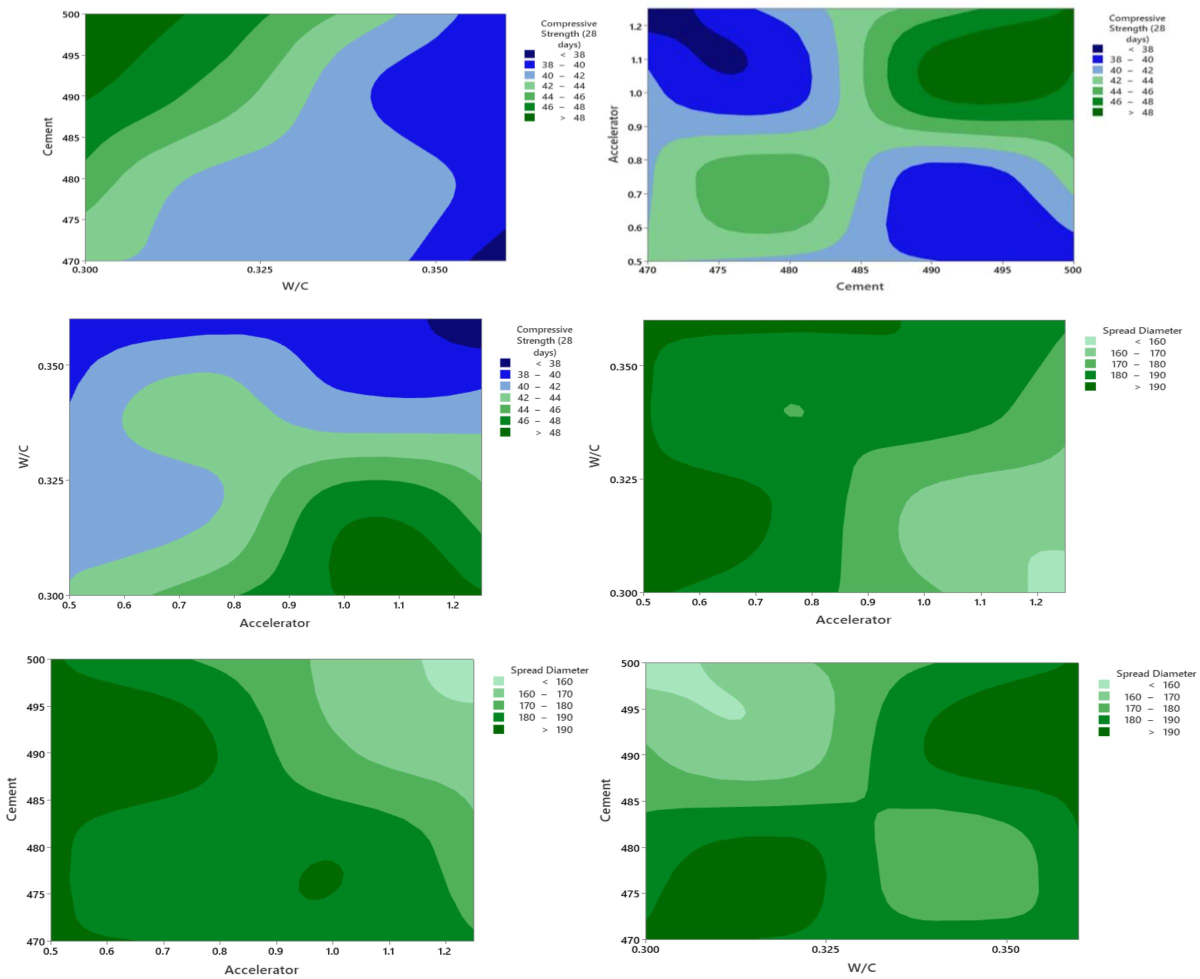


**Figure 9.** Optimization results based on Taguchi method

As it can be seen in Figure 6, Figure 7, and Figure 8, the mixture required for the maximum spread diameter and the mixture required for the maximum compressive strength differ from each other. Therefore, a design obtained from the Taguchi Orthogonal Array should be chosen as a mixture that will increase the spread diameter without much loss of compressive strength. Consequently, the mixing ratios given in Table 7 are chosen by the literature results [36,40,41]. Prediction was carried out for the optimum mixture. 10 samples were prepared from the mixture obtained from Taguchi, and their tests were performed for validation. Test results and prediction results obtained from the optimum mixture are given in Table 8.

**Table 7.** Optimum mixture design

| Silica Sand (kg) | Cement (kg) | W/C | Accelerator (% by wt. of cement) | Hyperplasticizer (% by wt. of cement) |
|---|---|---|---|---|
| 500 | 480 | 0.32 | 1.00 | 0.50 |

**Table 8.** Optimum mixture design validation test results

| Tests | Prediction | Experimental Results | Ratio |
|---|---|---|---|
| Spread Diameter | 179.12 | 184 | 1.0272 |
| Compressive Strength (MPa, 1 day) | 4.58 | 4.37 | 0.954 |
| Compressive Strength (MPa, 28 days) | 44.73 | 43.26 | 0.967 |

## 4. CONCLUSION

In this paper, optimization was performed for rapid-setting and high workability concrete added accelerator using the Taguchi method. Validation tests were conducted for the optimum mixture obtained from the Taguchi optimization. The main conclusions are given below:

- Accelerators positively affect the compressive strength up to a certain level which is %1.
- Accelerators increase early compressive strength, due to their contribution to ettringite formation.
- The mixture obtained by Taguchi optimization can be used in the precast industry that requires rapid production. Especially, it will be much more convenient to use in precast connection points.
- Concrete with high initial strength and high workability was obtained with little loss of final strength by using Taguchi optimization.
- More detailed optimization can be performed using genetic algorithms. These results should be compared with optimization results in this study.

## ACKNOWLEDGEMENT

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## DECLARATION OF ETHICAL STANDARDS

The authors of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

## AUTHORS' CONTRIBUTIONS

**Mustafa Tolga ÇÖĞÜRCÜ:** Performed the experiments and analyse the results.

**Mehmet UZUN:** Performed the experiments and analyse the results. Wrote the manuscript.

## CONFLICT OF INTEREST

There is no conflict of interest in this study.

## REFERENCES

[1] Yang J., Guo T. and Chai S., "Experimental and numerical investigation on seismic behaviours of beam-column joints of precast prestressed concrete frame under given corrosion levels", ***Structures***, 27: 1209–1221, (2020).

[2] Zhang C., Li H. and Gao W., "Development of a novel friction damped joint for damage-plasticity control of precast concrete walls", ***Engineering Structures***, 219: 110850, (2020).

[3] Martin, Leslie D., and Christopher J. Perry E. "Precast and prestressed concrete", (Vol 1). PCI Design Handbook, ***Prestressed Concrete Institute***, (2004).

[4] Shi C. and Day R.L., "Pozzolanic reaction in the presence of chemical activators. Part I. Reaction kinetics", ***Cement and Concrete Research***, 30: 51–58, (2000).

[5] Singh N.B., Singh V.D., Rai S. and Chaturvedi S., "Effect of lignosulfonate, calcium chloride and their mixture on the hydration of RHA-blended portland cement" ***Cement and Concrete Research***, 32: 387–392, (2002).

[6] Liu Z., Lou B., Barbieri D.M., Sha A., Ye T. and Li Y., "Effects of pre-curing treatment and chemical accelerators on Portland cement mortars at low temperature (5 °C)", ***Construction and Building Materials***, 240: 117893, (2020).

[7] Yum W.S., Suh J Il., Sim S., Yoon S., Jun Y. and Oh J.E., "Influence of calcium and sodium nitrate on the strength and reaction products of the CaO-activated GGBFS system", ***Construction and Building Materials***, 215: 839–848, (2019).

[8] Ghosh D., Abd-elssamd A., John Z. and Hun D., "Development of high-early-strength fiber-reinforced self-compacting concrete", ***Construction and Building Materials***, 266: 121051, (2021).

[9] Chang C.Y., Huang R., Lee P.C. and Weng T.L., "Application of a weighted Grey-Taguchi method for optimizing recycled aggregate concrete mixtures", ***Cement and Concrete Composites***, 33: 1038–1049, (2011).

[10] Fattahi Amirdehi H.R., Aliha M.R.M., Moniri A. and Torabi A.R., "Using the generalized maximum tangential stress criterion to predict mode II fracture of hot mix asphalt in terms of mode I results – A statistical analysis", ***Construction and Building Materials***, 213: 483–491, (2019).

[11] Aliha M.R.M. and Ayatollahi M.R., "Rock fracture toughness study using cracked chevron notched Brazilian disc specimen under pure modes I and II loading - A statistical approach", ***Theoretical and Applied Fracture Mechanics***, 69: 17–25, (2014).

[12] Dantas A.T.A., Batista Leite M. and De Jesus Nagahama K., "Prediction of compressive strength of concrete containing construction and demolition waste using artificial neural networks", ***Construction and Building Materials***, 38: 717–722, (2013).

[13] Zhang J., Ma G., Huang Y., Sun J., Aslani F. and Nener B., "Modelling uniaxial compressive strength of lightweight self-compacting concrete using random forest regression", ***Construction and Building Materials***, 210: 713–719, (2019).

[14] Zhang J., Li D. and Wang Y., "Toward intelligent construction: Prediction of mechanical properties of manufactured-sand concrete using tree-based models", ***Journal of Cleanear Production***, 258: 120665, (2020).

[15] Sharifi E., Sadjadi S.J., Aliha M.R.M. and Moniri A., "Optimization of high-strength self-consolidating concrete mix design using an improved Taguchi optimization method", ***Construction and Building Materials***, 236: 117547, (2020).

[16] Tanyildizi H. and Şahin M., "Application of Taguchi method for optimization of concrete strengthened with polymer after high temperature", ***Construction and Building Materials***, 79: 97–103, (2015).

[17] Joshaghani A., Ramezanianpour A.A., Ataei O. and Golroo A., "Optimizing pervious concrete pavement mixture design by using the Taguchi method", ***Construction and Building Materials***, 101: 317–325, (2015).

[18] Zhang J., Li D. and Wang Y., "Predicting tunnel

squeezing using a hybrid classifier ensemble with incomplete data", ***Bulletin of Engineering Geology and Environment***, 79: 3245–3256, (2020).

[19] Zhang J., Huang Y., Wang Y. and Ma G., "Multi-objective optimization of concrete mixture proportions using machine learning and metaheuristic algorithms", ***Construction and Building Materials***, 253: 119208, (2020).

[20] Zhang J., Li D. and Wang Y., "Predicting uniaxial compressive strength of oil palm shell concrete using a hybrid artificial intelligence model", ***Journal of Building Engineering***, 30: 101282, (2020).

[21] Sun Y., Zhang J., Li G., Wang Y., Sun J. and Jiang C., "Optimized neural network using beetle antennae search for predicting the unconfined compressive strength of jet grouting coalcretes", ***International Journal of Numerical Analytical Methods Geomechanics***, 43: 801–813, (2019).

[22] Sun J., Zhang J., Gu Y., Huang Y., Sun Y. and Ma G., "Prediction of permeability and unconfined compressive strength of pervious concrete using evolved support vector regression", ***Construction and Building Materials***, 207: 440–449, (2019).

[23] Chou C.S., Yang R.Y., Chen J.H. and Chou S.W., "The optimum conditions for preparing the lead-free piezoelectric ceramic of Bi0.5Na0.5TiO3 using the Taguchi method", ***Powder Technology***, 199: 264–271, (2010).

[24] Türkmen İ., Gül R., Çelİk C. and Demirboğa R., "Determination by the taguchi method of optimum conditions for mechanical properties of high strength concrete with admixtures of silica fume and blast furnace slag", ***Civil Engineering and Environmental Systems***, 20: 105–118, (2003).

[25] Ferdous W., Manalo A. and Aravinthan T., "Bond behaviour of composite sandwich panel and epoxy polymer matrix: Taguchi design of experiments and theoretical predictions.", ***Construction and Building Materials***, 145: 76–87, (2017).

[26] Prusty J.K., and Pradhan B., "Multi-response optimization using Taguchi-Grey relational analysis for composition of fly ash-ground granulated blast furnace slag based geopolymer concrete", ***Construction and Building Materials***, 241: 118049, (2020).

[27] Celik N., Pusat G. and Turgut E., "Application of Taguchi method and grey relational analysis on a turbulated heat exchanger", ***International Journal of Thermal Sciences***, 124: 85–97, (2018).

[28] Teimortashlu E., Dehestani M. and Jalal M., "Application of Taguchi method for compressive strength optimization of tertiary blended self-compacting mortar", ***Construction and Building Materials***, 190: 1182–1191, (2018).

[29] Chen W.C. and Kurniawan D., "Process parameters optimization for multiple quality characteristics in plastic injection molding using Taguchi method, BPNN, GA, and hybrid PSO-GA", ***International Journal of Precision Engineering and Manufacturing***, 15: 1583–1593, (2014).

[30] Gopalsamy B.M., Mondal B. and Ghosh S., "Taguchi method and anova: An approach for process parameters optimization of hard machining while machining hardened steel", ***Journal of Scientific and Industrial Research***, 68: 686–695, (2009).

[31] Mehta A., Siddique R., Singh B.P., Aggoun S., Łagód G. and Barnat-Hunek D., "Influence of various parameters on strength and absorption properties of fly ash based geopolymer concrete designed by Taguchi method", ***Construction and Building Materials***, 150: 817–824, (2017).

[32] Jafari K., Tabatabaeian M., Joshaghani A. and Ozbakkaloglu T., "Optimizing the mixture design of polymer concrete: An experimental investigation", ***Construction and Building Materials***, 167: 185–196, (2018).

[33] TS EN 12350-5, "Testing fresh concrete- Part 5: Flow table test", ***Turkish Standard***, (2010).

[34] TS EN 12390-2, "Testing hardened concrete- Part 2: Making and curing specimens for strength tests", ***Turkish Standard***, (2010).

[35] TS 3114, "Determination of compressive strength of concrete test specimens", ***Turkish Standard***, (1998).

[36] Salvador R.P., Rambo D.A.S., Bueno R.M., Lima S.R. and Figueiredo A.D., "Influence of accelerator type and dosage on the durability of wet-mixed sprayed concrete against external sulfate attack", ***Construction and Building Materials***, (2020).

[37] Yang H., Yan Y. and Hu Z., "The preparation of nano calcium carbonate and calcium silicate hardening accelerator from marble waste by nitric acid treatment and study of early strength effect of calcium silicate on C30 concrete", ***Journal of Building Engineering***, 32: 101507, (2020).

[38] Min T.B., Cho I.S., Park W.J., Choi H.K. and Lee H.S., "Experimental study on the development of compressive strength of early concrete age using calcium-based hardening accelerator and high early strength cement", ***Construction and Building Materials***, 64: 208–214, (2014).

[39] Zhang L., Yamauchi K., Li Z., Zhang X., Ma H. and Ge S., "Novel understanding of calcium silicate hydrate from dilute hydration", ***Cement and Concrete Research***, 99: 95–105, (2017).

[40] Do T.A., Hoang T.T., Bui-Tien T., Hoang H.V., Do T.D. and Nguyen P.A., "Evaluation of heat of hydration, temperature evolution and thermal cracking risk in high-strength concrete at early ages", ***Case Studies in Thermal Engineering***, 21: 100658, (2020).

[41] Shen D., Wen C., Zhu P., Wu Y. and Yuan J., "Influence of Barchip fiber on early-age autogenous shrinkage of high strength concrete", ***Construction and Building Materials***, 256: 119223, (2020).