Optimization of Compressive Strength of Concrete Added Glass Powder Using Taguchi Methods

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ABSTRACT

Concrete is a widely used material all over the world. Conventional concrete production contains water, cement, coarse and fine aggregate. Concrete production process has many developments owing to needs on building industry. These developments in concrete are generally classified as high strength, ductility, impermeability. In conventional concrete, optimization of concrete strength is easy with linear and nonlinear regression models. However, the contribution of admixtures in concrete such as super plasticizer, glass powder and all kind of fiber make complicate to predict compressive strength. In this study, the effect of glass powder (GP), super plasticizer and spread diameter effect on the compressive strength optimization of GP added concrete mixes. %10, 15 and 20 of (% wt.) GP was added into the concrete mixes by weight of cement. Concrete compressive strength results were obtained for 80 different mixes. These results were used to optimize the compressive strength of specimens with Taguchi methods.

Keywords - Compressive Strength, Glass Powder, Taguchi Methods, Prediction of Compressive Strength

1. INTRODUCTION

Many studies have been carried out to reduce environmental pollution and carbon dioxide emissions due to the increasing greenhouse gas effects in the world. Cement production facilities are also one of the industrial plants with the highest carbon dioxide emissions. The share of carbon dioxide emission in global warming is around 65%, and cement production has a share of 7% in carbon dioxide emissions [1]. The fact that the concrete produced in the United States in 2007 was approximately 800 million tons and that the total amount of concrete produced in the world is 11 billion tons, it is necessary to carry out studies to reduce the use of cement used in the concrete [2-4].

There is a high increase in industrial wastes along with the developing technology and industrial industry. Refuse disposal or recycle these wastes are a significant study topic due to the increase in industrial wastes [1, 5]. Glass wastes are materials that are sparingly soluble in nature and difficult recycling such as other industrial wastes [3]. On the other hand, glass wastes can be used instead of cement using due to rich silica structure of glass wastes. GP provides additional advantages by means of its pozzolanic property. Produces calcium silica hydrate (C-S-H) structures by reacting with portlandite ($Ca(OH)_2$) formed during cement hydration of amorphous silica (SiO_2) contained GP [6-9]. The reaction of the GP is as follows [10]:

$$SiO2(s)+Ca2+(aq)+2OH-(aq)=n1CaO.SiO2.n2H2O(s) \quad (1)$$

The biggest problem in the concrete work is the high number of samples. In recent years, statistical methods have been used to solve this problem. One of the statistical methods is Taguchi that is in demand due to use both analysis and optimization by researchers [11, 12]. Taguchi method is one of the experimental design methods that try to reduce the variability of product and process by selecting the most appropriate combination of levels against uncontrollable factors which form variability [13, 14].

In recent years, many studies have been performed by using the taguchi method. Arici and Kelestemur analyzed the compressive strength of mortars with mill scale by taguchi method [14]. Teimortashlu et all applicated taguchi method for compressive strength optimization of tertiary blended self-compacting mortar [15]. Panagiotopoulou et all applicated Taguchi method for the composition optimization of alkali activated fly ash binders [16]. Hadi et all designed geopolymer concrete with GGBFS at ambient curing condition by using Taguchi method [17].

In the current research, fresh and hardened properties of GP added concrete were investigated using the Taguchi method. four different mixes were designed with the same water/powder ratio. Their compressive strength and spread diameter are reported and discussed.

2. MATERİALS AND METHODS

2.1. Experimental Study

All test samples were produced using locally available materials.
Cement: Cement used as cement CEM I 42.5 R according to TS EN 197-1 by Konya Cement Company. Cement is used 330 kg/m^3 in all samples.
Superplasticizer: A high range water reducer without retarding was used (Sefar Conslumper 5252 HZ). Properties of superplasticizer are given in Table 1.

Table 1. Properties of superplasticizer

Colour	Dark Brown
Density	1.06
Usage Dosage	0.8-2.0
Ph Value	3.8

Glass Powder: The glass powder was obtained by grinding to a maximum grain size of 0.005 cm (Figure 1). Chemical properties of cement and GP are given in Table 2.

Figure 1. Glass powder

Water: Fresh tap water was used with water/binder ratio w/b=0.48

Table 2. Chemical properties of cement and GP

Components	**Cement**	**Glass Powder (GP)**
SiO_2	20.83	71.79
Al_2O_3	5.14	2.23
Fe_2O_3	3.01	0.28
CaO	63.87	10.51
MgO	2.47	0.84
SO_3	2.5	-
Na_2O	0.15	13.83
TiO_2	-	0.1
Cr_2O_3	-	0.01
K_2O	-	0.17

Compressive strength test was carried out on 15*15*15 cm cubes and according to ASTM C39-86. The capacity of the compression machine used is 2000 kN.

Concrete mix design parameter is given in Table 3 for each mix.

Table 3. Mix design

Mix Design	Cement (kg/m^3)	Water (kg/m^3)	W/B *	SP ** (g)	GP (kg/m^3)	Aggregate (kg/m^3)		
						0-5	5-15	15-25
A	330	157	0.48	250	-	1120	390	385
B	297	157	0.48	260	33	1118	389	384
C	280.5	157	0.48	280	49.5	1116	387	382
D	264	157	0.48	290	66	1114	386	379

* W/B: Water/Binder (Cement+Glass Powder)
** SP: Super plasticizer

2.2. Parameter Design Methodology

Taguchi parameter design method is a powerful method for optimizing and designing the characteristic performance of a product. Optimization quality characteristic minimizes sensitivity to noise (S/N) factors [18]. S/N is used for uncontrollable factors. Control factors are given in Table 4.

Table 4. Control factors and Average Compressive Strength Test Results (7, 28 days)

Mix design	GP content (%)	Plasticizer amount (g)	Spread Diameter (mm)	Average Compressive Strength (7 days, MPa)	Average Compressive Strength (28 days, MPa)
A	0	250	128.1	20.25	29.05
B	10	260	124.5	21.08	29.69
C	15	280	118.5	21.36	30.62
D	20	290	114.7	22.44	31.12

2.3. Taguchi's Orthogonal Array Approach of Experimental Design

Taguchi's target is to consistently develop products that reach the target value. The variation in the target value should be minimized [18]. In other words, quality is minimized by minimizing deviation from the target. The mixes are produced as 80 different mixes.

3. RESULTS AND DISCUSSION

Fresh concrete experimental test results are given Table 5. It was obtained that the increase in GP content, decreased the average spread diameter of the mixes. Maximum average spread diameter was recorded with the mix A.

Maximum average compressive strength test results were found as 31.12 MPa with Mix design D. GP content improved the compressive strength property of the concrete mixes. However, workability of the mixes worsened by the GP content increase.

Table 5. Fresh concrete experimental test results

Mix design	GP content (%)	Average spread diameter (mm)
A	0	128.1
B	10	124.5
C	15	118.5
D	20	114.7

The S/N ratios resulting from the quadratic loss function are expressed on the decibel (dB) scale which is the sound expression. A formula is used to calculate the S/N ratio. This formula depends on the objective function. In general, the following functions are used as objective functions [18]:

- Larger is the better
- Smaller is the better
- Nominal is the best

S/N ratios of compressive strength test results are given in Table 6. S/N ratios of the control factors in Figure 2. The objective function is chosen as larger is the higher for compressive strength.

Table 6. S/N ratios of compressive strength test results (28 days)

Level	Spread diameter	Plasticizer	GP content
1	58.70	52.40	43.93
2	39.42	53.06	39.49
3	45.85	49.57	42.87
4	30	55.18	42.98
5	38.46		
6	40.72		
7	52.02		
8	36.50		
9	42.92		
10	32.50		
11	39.91		
12	36.88		
13	54.46		
14	51.87		
Delta	5.92	6.61	4.45
Rank	2	1	3

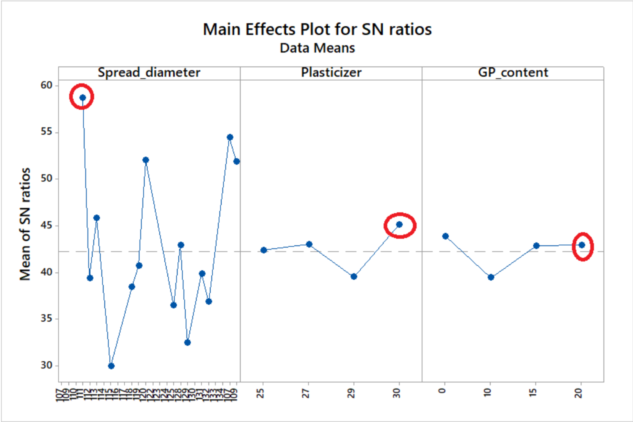

Figure 2. Main effect plots (S/N ratio, larger is better)

Plasticizer amount was found as the most significant factor influencing the compressive strength of the specimens. Optimum factors are obtained as spread diameter of 113 mm, plasticizer amount of 300g, and GP content of 20 % as shown in Figure 2.

Table 7 shows that the analysis of variance for compressive strength. A most important effecting factor was plasticizer amount.

Table 7. Analysis of variance for compressive strength (28 days)

Source	DF	SS	MS
GP content	3	25.93	8.64
Plasticizer	12	771.72	64.31
Spread diameter	39	16.13	0.41
Error	6	3.61	0.15
Total	60	817.37	

18 cubic specimens were prepared as per the optimization results. 7- and 28-days compressive strength test results were recorded (Table 8).

Table 8. Validation of Optimization Test Results (7, 28 days)

Mix design	GP content (%)	Plasticizer amount (g)	Average Compressive Strength (7 days, MPa)	Average Compressive Strength (28 days, MPa)
D	20	300	23.52	33.27

Validation of the optimization results was performed with compressive strength tests. Compressive strength values were enhanced with the optimization results.

GP content and average compressive strength (7-28 days) are given in Figure 3. Maximum strength values were higher than 31 Mpa with the 20 % GP content.

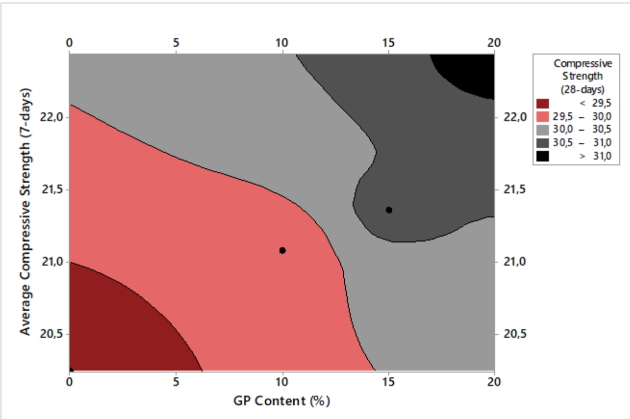

Figure 3. GP content-average compressive strength (7-28 days)

Plasticizer amount and average compressive strength (7-28 days) are given in Figure 4. Mixes with 290 plasticizer content had the maximum compressive strength values.

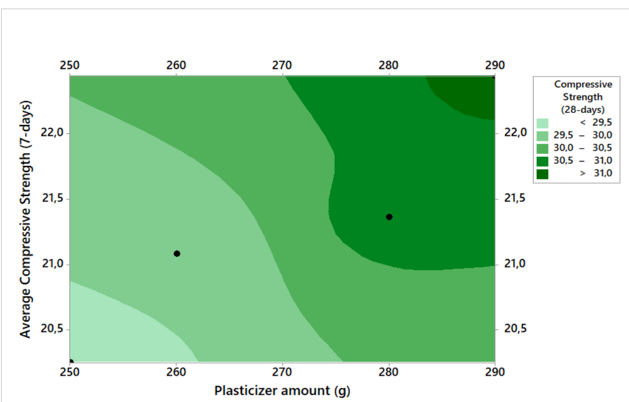

Figure 4. Plasticizer amount-average compressive strength (7-28 days)

4. CONCLUSIONS

Taguchi method was utilized for the optimization of Glass Powder added to concrete. Spread diameter, plasticizer amount and the GP content were taken as controlling factors during the optimization process. The analysis results showed that the proposed Taguchi optimization technique could be used in order to enhance the compressive strength test results.

Experimental test results also reflected that GP content up to 20 %, improves the compressive strength test results. Future studies can be conducted on the other mechanical properties of the concrete.

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