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A Taguchi approach for investigating the engineering properties of concretes incorporating barite, colemanite, basaltic pumice and ground blast furnace slag

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HIGHLIGHTS

- Taguchi method used for reducing the number of samples.
- Effectiveness of the mineral additives determined by Taguchi method.
- Barite is the most effective parameter at early ages.
- BFS is the most effective parameter at later ages.

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ABSTRACT

Natural and artificial mineral additives have been frequently used for improving the physical, mechanical and durability properties of concrete in recent years. In this study four different mineral additives were used which are barite, colemanite, basaltic pumice and ground granulated blast furnace slag (BFS). Each mineral additive was used one by one and binary, ternary and quaternary combinations. Utilization of these mineral additives as fine aggregates and cement replacement material was investigated and the effect of these materials on compressive strength, splitting tensile strength, ultrasonic sound velocity, capillary water absorption and Böhme abrasion resistance were examined. The Taguchi method was also used to determine the optimum working conditions for each parameter and to reduce the number of experiments. Besides, contribution of each material on test results was also determined by ANOVA. According to the analysis, it was seen that blast furnace slag and colemanite were the two most effective parameters on results in general.

1. Introduction

Concrete is the most commonly used construction material in the world. It became more common compared to the other building materials due to its features of being economic, easy formable, more durable, consuming less energy during production, being aesthetic and easily producible everywhere aesthetic. Nevertheless, in some cases conventional concrete remains incapable. Today, not only the strength of the concrete but also its durability is required. In this case, the durability related concrete design comes to the forefront. The type of concrete which provides both high strength and high durability is called high performance concrete [1].

High performance concrete production is generally provided by using natural and artificial pozzolans such as fly ash, silica fume, blast furnace slag, metakaolin and various organic ashes [1].

A serious number of recent studies stated that using ground granulated blast furnace slag both as fine aggregates and cement substitution admixture had successful results in terms of mechanical, durability and microstructure properties [2–5]. Also the convenience of basaltic pumice as fine aggregate in concrete was investigated and different engineering properties were tested by various researchers. The results showed that basaltic pumice incorporating mixtures have better workability and abrasion resistance than conventional concrete. Also pumice aggregate used samples have a superior shock absorbing property. Research results showed that basaltic pumice as fine aggregates could be used for produc-

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tion of lightweight concrete [4,6–9]. It is also known that pumice is used for producing other construction materials such as bricks [10].

On the other hand, it is known that using granulated blast furnace slag and basaltic pumice as cement substitution material has an increasing effect on durability and mechanical properties [11–13].

Generally the aggregates which are used for heavyweight concrete production are either natural aggregates such as barite, limonite, magnetite containing iron ore or artificial aggregates such as iron and lead particles. The most important difference between conventional concrete and heavyweight concrete is the unit weight [14–16]. Investigations showed that heavyweight concretes containing barite had better freeze – thaw and radiation resistance [17,18].

In recent years, extensive researches were carried out about how to use boron, boron minerals (colemanite, kernite, ulexite etc.) or boron wastes in concrete. The economic value of the intermediate products produced from boron minerals is quite high. Researches which used colemanite wastes as concrete admixture showed that they prevented the strength gaining but they significantly increased the compressive strength even when they were used in small amounts [19].

Turkey has significant amount of boron, barite and pumice reserves. These products are considered as high competitiveness products. At the same time as a result of the developing industry high amounts of industrial by-products and wastes emerge. In this study the compressive strength, splitting tensile strength, ultrasonic sound velocity, capillary water absorption and Böhme abrasion resistance of concrete samples were studied including various amounts of pumice, barite, blast furnace slag and colemanite.

2. Experimental study

2.1. Materials

TS EN 197-1 CEM I 42.5 type cement produced in Turkey was used for the study. Barite was obtained from Barite Mine Turk Inc. in Osmaniye, colemanite was selected from ETI Mine Works, pumice was obtained from Adana Cement and blast furnace slag was selected from ISDEMIR (Iskenderun Iron and Steel Works Co.). All materials were obtained as grounded from the suppliers. The chemical and physical properties of the materials used in the study are given in Table 1. Aksu river aggregate was used as natural aggregate. As fine aggregate 0–4 river sand was used and as coarse aggregates 4–11 and 11–22 mm sized river aggregates were used. The grain distribution and the physical properties of the aggregates are shown Table 2 respectively.

Table 2
Physical properties of aggregates.

Property	Sand (0–4 mm)	4–11 mm Aggregate	11–22 mm Aggregate
Specific gravity (g/cm^3)	2.65	2.74	2.73
Compressed unit weight (g/cm^3)	1.94	1.60	1.57
Loose unit weight (g/cm^3)	1.74	1.59	1.57
Water absorption (%)	3.41	1.21	0.40

2.2. Design of experiments

The design of the experiments was carried out by using the Taguchi technique. By this way, it was possible to achieve more extensive results with less number of experiments. Therefore the time and cost saving was ensured. Experimental study can be designed easily by obtaining the optimum working conditions of the parameters affecting the results with the help of the Taguchi method [20]. A systematic approach is needed to apply the Taguchi method to the solution of problems. A systematic and efficiency approach for this purpose is given in Fig. 1.

The operations of the flowchart can be grouped into 13 operational steps for achieving design optimization. These steps are the followings:

- Determining of the problem and organizing the team.
- Determining the performance characteristic(s) and the measuring system.
- Determining the variables (parameters) affecting the performance characteristic(s).
- Conducting the screening design.
- Determining the interactions to be examined.
- Selecting appropriate OAs and assigning the variables to the suitable columns.
- Determining the loss function(s) and performance statistics.
- Conducting experiments and recording the results.
- Analyzing data and selecting the optimum value of the controllable variables.
- Testing the results.
- Establishing tolerance design.
- Evaluation, implementation and observation [21,22].

Table 1
Chemical and physical analysis results of materials.

Compounds (%)	Cement	Basaltic Pumice	Blast Furnace Slag	Colemanite	Barite
Chemical analysis results					
SiO_2	18.63	47.63	43.71	4	4
Al_2O_3	5.38	15.99	11.14	0.4	0.84
Fe_2O_3	2.80	11.24	1.21	0.08	0.7
CaO	64.39	9.65	32.28	26	1.7
MgO	3.73	8.05	8.42	3	0.3
SO_3	2.63	–	–	–	–
Na_2O + K2O	0.62	–	–	0.35	0.8
SrSO	–	–	–	1.5	0.65
B_2O_3	–	–	–	40	–
$BaSO_4$	–	–	–	–	89.56
MnO	–	–	–	–	0.42
Loss of ignition (%)	0.58	0.73	–	24.6	1.03
Physical analysis results					
Specific Weight (g/cm^3)	3.20	2.91	2.86	2.47	3.95
Fineness	3497 cm^2/g	3710 cm^2/g	5500 cm^2/g	75 μm	75 μm