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July 9-11, 2021
Paris, FRANCE

FULL TEXTS BOOK

Edited by
Prof. Dr. Osman ERKMEN
Nurlan AKHMETOV

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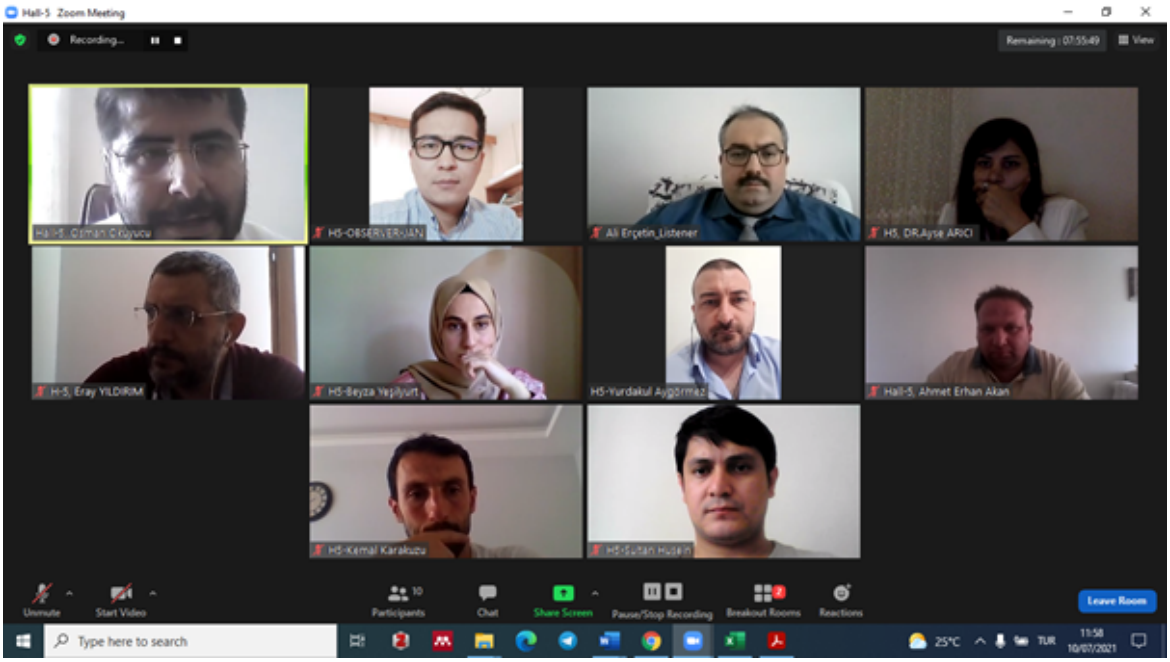
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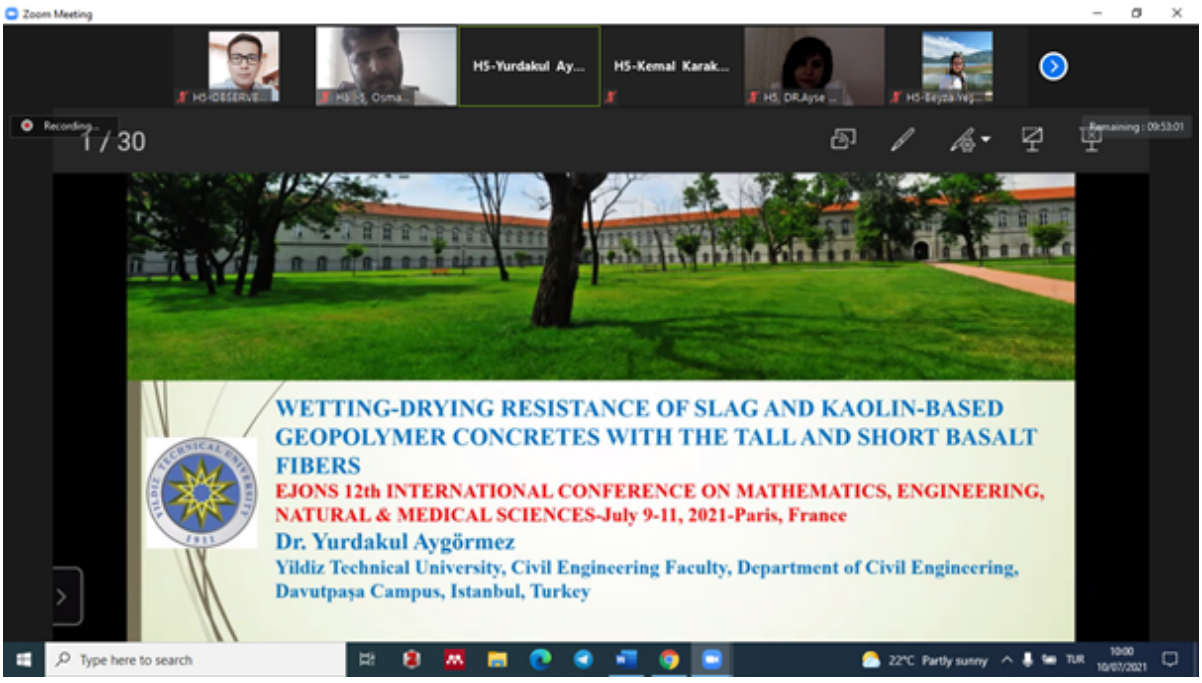
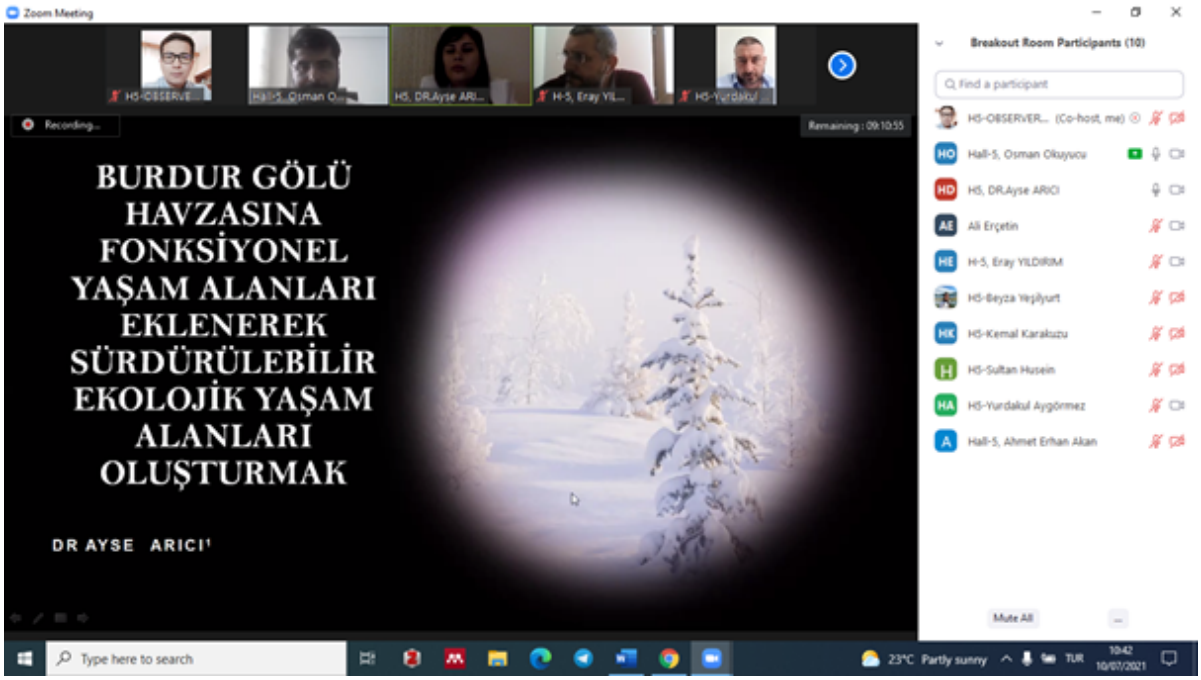
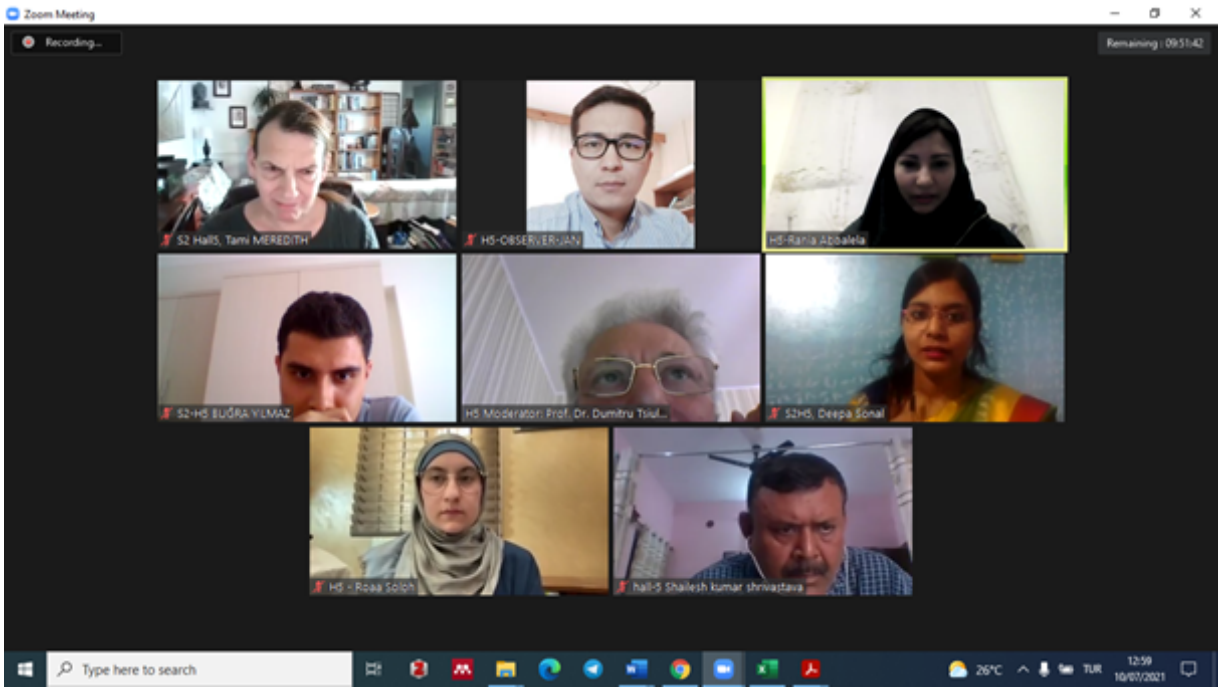


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	Senad Hodžić	High International school Cazin, Bosnia and Herzegovina
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WETTING-DRYING RESISTANCE OF SLAG AND KAOLIN-BASED GEOPOLYMER CONCRETES WITH THE TALL AND SHORT BASALT FIBERS

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ABSTRACT

Geopolymer concrete is known as cementless concrete according to the literature. High CO_2 emission in cement production has attracted the attention of many environmentalist human societies by creating negative effects on environmental problems and therefore human health. Increasing environmental pollution at a level that will affect the world has led to an increase in environmental sensitivity due to the fact that cement factories produce more than cement consumption in the market and have an excess of CO_2 emissions. Due to this situation, many types of research have started to be made on the use and recycling of alternative materials to cement. Within the scope of this study, different binder materials were used interchangeably to produce sustainable and environmentally friendly geopolymer concrete. Slag obtained as a by-product in the production of cast iron and natural and cheap kaolin were used as substitutes in geopolymer concrete. Kaolin and slag were substituted in four different proportions (15%, 30%, 45%, and 60% by weight). In addition, in the series with the highest result, two different basalt fibers with different lengths (tall basalt fiber (TBF) and short basalt fiber (SBF)) were substituted with each other so that the total ratio was 2% by weight (2%TBF, 1.6%TBF+0.4%SBF, 1.2%TBF+0.8%SBF, 0.8%TBF+1.2%SBF, 0.4%TBF+1.6%SBF). The 28 and 90 days compressive strength and ultrasonic pulse velocity (UPV) results of the geopolymer concretes were found. According to the results, it was positively affected by the substitution of kaolin up to 30% as it would increase geopolymerization. Tall basalt fiber gave the highest result by limiting cracks up to 1.2%. In order to see the behavior in the durability effect, a wetting-drying test consisting of 10 and 50 cycles was applied. Geopolymer concretes showed significant resistance to the wetting-drying test.

Keywords: Geopolymer concrete, Kaolin, Slag, Basalt fiber, Wetting-drying.

1. INTRODUCTION

In Ordinary Portland Cement production, a lot of energy consumption occurs with limestone decomposition. The cement industry is responsible for about 7% of CO_2 emissions and causes environmental problems [1-2]. Alternatively, alkali-activated or geopolymer composites create a durable and sustainable approach. Geopolymer is an inorganic polymer type that can be produced with different industrial waste materials and by-products and has a room temperature hardening property. Thus, it acts as a binder in concrete like Ordinary Portland Cement. In addition, it is more advantageous than Ordinary Portland Cement in gaining early strength and resistance to durability conditions (high temperature and aggressive chemicals). Aluminosilicate mineral content (silicon, aluminum, and oxygen ratios) is important in binder selection for geopolymer. High silicon and aluminum content is important for geopolymerization. The most commonly used aluminosilicate binders are fly ash and blast furnace slag. The production increase in waste industrial products allows such materials to be used as raw materials. In addition, considering the global problems of these waste products, innovative and environmentally friendly materials are obtained in case of reuse [1].

Slag with significant calcium content has different properties than fly ash with the low calcium content. If fly ash is used alone, the slag must be blended to achieve room temperature hardening. Blast furnace slag is obtained as a by-product in the combustion process in the cast iron industry [2]. Blast furnace slag is a non-metallic by-product produced by mixing iron with fondants and coke and melting them in furnaces [3]. In the furnace crucible, slag is obtained at the top and cast iron is obtained at the bottom. It is fine-grained and has a high potential for hydraulic activity due to the fact that the oven is cooled with plenty of water. This feature provides an important advantage in geopolymer production. In slag mixed systems, the reaction rate increases with the amount of slag and activator. Despite this advantage, it causes problems such as creating rapid slump loss and reducing workability. Because of this, instead of using it alone, using it with a different binder will support the solution of the problem [4-5].

Kaolin is in white or near-white shading with a pseudo-hexagonal precious stone alongside plates which are some vermicular stacks and bigger books. However, when considered as a binding material for geopolymer, it creates a weak structure with low reactivity that requires a certain time to gain strength [6]. In this case, the particle shape of the kaolin is effective. The fact that kaolin has a small surface area causes the alkali activator to dissolve Si and Al at a minimum rate and thus obtain low strength. The reaction of the kaolin and alkali activator slowly penetrates the structure from the surface and the edge. Due to this situation, it does not create sufficient strength if used alone. Despite these conditions, kaolin has good volume stability in water and it provides strength increase with increasing age, which is its positive feature. Pozzolanic activity is higher in metakaolin produced by calcining kaolin at high temperature [7]. However, this also brings a significant amount of energy and costs. Due to these conditions, it will be an important advantage to be used with different binders with high calcium oxide ratios to be used without calcination [6, 8].

The fiber addition to the geopolymer composite affects the durability and mechanical properties by changing the degree of geopolymerization. The use of different fibers such as woven fabric, carbon, wood, steel, glass, and basalt has been used extensively in the construction sector [9-11]. These studies have been also carried out intensively in geopolymer concrete. However, in general, fiber types have been used alone in these studies. However, studies on the use of different types of fibers by combination are limited. With this method, it is possible to take advantage of fiber types. Basalt fiber is an important support in limiting cracks. According to Arunagiri et al. [12], it has been observed that when 2% basalt fiber by volume was added to geopolymer concrete, it increased the mechanical properties.

Geopolymer concrete is an environmentally friendly and sustainable material that has significant advantages over Ordinary Portland Cement-based concrete. The realization of this situation with low energy consumption provides an important advantage. It is important to evaluate the slag obtained as a by-product of cast iron and natural and common kaolin together in the geopolymer concrete production. Kaolin and slag were substituted in four different proportions (15%, 30%, 45%, and 60% by weight) in this study. In addition, in the series with the highest result, two different basalt fibers with different lengths were substituted with each other so that the total ratio was 2% by weight (2%TBF, 1.6%TBF+0.4%SBF, 1.2%TBF+0.8%SBF, 0.8%TBF+1.2%SBF, 0.4%TBF+1.6%SBF). The results of 28 and 90-day compressive strength and UPV of the obtained geopolymer concretes were found, and the wetting-drying test was also applied. After 10 and 50 cycles of wetting-drying test, compressive strength, UPV, and weight changes were investigated while the visual examination was also carried out.

2. MATERIAL AND METHODS

In this study, slag obtained from Akçansa Company was used as a binding material. While the Blaine-specific surface of the slag is 4500 cm^2/g, its specific gravity is 2.91. The other binder material, kaolin, was supplied from Kaolin EAD Company and its specific gravity is 2.52. The Blaine-specific surface area of the kaolin is 14.6 m^2/g. The chemical properties of binder materials are given in Table 1. In addition, basalt fibers with a length of 24 mm and 12 mm were used in this study. The properties of tall and short basalt fibers are shown in Table 2. 12M of sodium hydroxide and sodium silicate with SiO_2/Na_2O ratio of 3.29 were used for the alkali activator solution.

Tablo 1. Chemical composition of cement and slag (%)

Chemical analysis, %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	L.O.I.
Slag	40.60	12.83	1.37	36.08	6.87	0.68	0.79	0.78
Kaolin	47.40	40.50	0.80	0.60	0.30	0.50	0.30	9.60

Tablo 2. The basalt fibers' properties

Fiber type	Length (mm)	Modulus of elasticity (GPa)	Diameter (μm)	Tensile strength (MPa)	Elongation (%)	Density (g/cm^3)
Tall basalt fiber	24	89	20	4800	3.15	2.80
Short basalt fiber	12	89	13	4100	3.15	2.80

10 series were prepared for this study. For the first 5 series, kaolin was replaced with slag in four different proportions (15%, 30%, 45%, and 60% by weight). In addition, in the series with the highest result, two different basalt fibers with different lengths were substituted with each other so that the total ratio was 2% by weight (2%TBF, 1.6%TBF+0.4%SBF, 1.2%TBF+0.8%SBF, 0.8%TBF+1.2%SBF, 0.4%TBF+1.6%SBF). Mixing details of the produced series are shown in Table 3. As coarse aggregates, crushed limestone aggregates of a maximum of 16 mm were used. The water absorption percentage and specific gravity of crushed limestone aggregate are 0.31% and 2.70, respectively. Conventional river sand was also used. It has a water absorption rate of 1.59% and a specific gravity of 2.61. A proper aggregate mix classification has been prepared. The mixture's fineness modulus is 4.09. Volume percentages of aggregates were held constant for all mixtures. In addition, MasterGlenium 51 was used as a water reducer to increase fluidity in the study. While preparing the mixture, firstly the dry mixture (binding materials+ aggregates) was put into the concrete mixer and mixed for 2 minutes. Then the superplasticizer added activator solution was added and mixed for a further three minutes. In the fibrous series, the fibers were added to the mixture at this stage. After the mixtures were placed in a 150 mm cube mold, they were exposed to vibration. All samples were demolded in a controlled room at 23±1°C 1 day after

casting. It was then kept in room conditions until the day of testing. Compressive strength and UPV tests were carried out on 28 and 90 days. In addition, a wetting-drying test was carried out at the end of 90 days. For the wetting-drying test, 10 and 50 cycles were applied. 1 cycle included drying for 24 hours at 65°C and soaking in the water for 24 hours at room temperature. After the wetting-drying tests, the results of UPV, compressive strength, and weight changes were found. In addition, a visual inspection was made.

Tablo 3. Mixture proportions

Component (%)	Kaolin	Slag	Short Basalt Fiber (%)	Tall Basalt Fiber (%)
1	-	100	-	-
2	15	85	-	-
3	30	70	-	-
4	45	55	-	-
5	60	40	-	-
6	45	55	-	2
7	45	55	0.4	1.6
8	45	55	0.8	1.2
9	45	55	1.2	0.8
10	45	55	1.6	0.4

3. RESULT AND DISCUSSION

The 28 and 90-day compressive strength and UPV results of 10 geopolymer concrete series prepared within the scope of this study and the results at the end of 10 and 50 cycles of the wetting-drying test are given in Figures 1-2. In addition, the weight change after the wetting-drying test is given in Figure 3. Slag was an important binder that had the potential to be used in geopolymer concrete. Due to its high CaO content, an exothermic reaction occurred. Due to the heat generated as a result of the reaction, the production of sodium aluminate hydrate (N-A-S-H) and calcium aluminate hydrate (C-A-S-H) was accelerated and a 3-D silico-aluminate structure network was formed. In addition, with the CaO content, hydration occurred and C-S-H gel was produced. With the combination of these two gels, the particles were tightly bound and a dense microstructure of the geopolymer was formed, increasing the compactness. This situation contributed to the hardened properties of the geopolymer concrete [13]. However, the increase in slag increased the demand for alkali activators. It led to a decrease in workability. Therefore, it was necessary to investigate the use of different binders with slag as a substitute instead of using it alone. Kaolin was an important alternative binder in this sense. With the addition of kaolin as a binder, the reaction process and physical properties were affected and the geopolymer matrix changed. Its fine particle size contributed to filling the pores and air voids of concrete samples. In addition, having small particles helped to create a denser aggregate mixture and increase strength. It was important for kaolin to be a good source of alumina and silica for geopolymerization. The inclusion of kaolin increased the reactive SiO_2 ratio for geopolymerization, allowing the formation of more Si-O-Al bonds. Thus, a denser tetrahedral aluminosilicate structure was formed. Because of this situation, the strength results increased with the use of 30% kaolin. The UPV test and the compressive strength results were in parallel. If it was used at higher rates, a weaker structure was formed due to the low reactivity of kaolin, and this situation negatively affected the strength

development of the geopolymer [14]. The effect of fiber lengths on mechanical properties was studied by using two different lengths of basalt fibers together as a substitute for a total of 2%. Since basalt fiber with 24 mm provided a longer anchorage by keeping the particles more robust than the basalt fiber with 12 mm, it provided higher mechanical properties by controlling the cracks. But here 1.2% ratio was critical. Workability was adversely affected by using longer basalt fiber than this ratio. This situation reflected negatively on mechanical properties [15]. The fiberless series with 30% kaolin substitution achieved 63.14 MPa and 71.25 MPa of compressive strengths after 28 days and 90 days, while UPV results were 4090 m/s and 4221 m/s, respectively. In the series using 1.2% tall basalt fiber, compressive strength of 72.64 MPa and 78.72 MPa was obtained after 28 days and 90 days, while UPV results were 4243 m/s and 4385 m/s, respectively.

The results of UPV, compressive strength and weight changes fluctuated due to the wetting-drying effect. According to the examination of the results, the results were increased after 10 cycles, while a decrease occurred after 50 cycles. These fluctuations were expected due to the severity of the regime affecting the concrete samples' integrity under the influence of service conditions. The wetting-drying and cooling-heating cycles were repeated. This caused hydration and evaporation to occur continuously. In this way, the crystallization of ions in water was repeated. Thus, expansion and shrinkage followed each other and internal stresses occurred in the pore structure that caused the strength to increase and decrease. The thermal expansion coefficient and drying shrinkage were the main reasons for this situation. On the other hand, heating the sample with the effect of wetting-drying caused an increase in density. Thus, geopolymerization was provided to be faster. Due to this situation, UPV and compressive strength results increased. While more geopolymerization occurred with the wetting stage, a denser structure was formed with drying, resulting in higher results. Having a high calcium content accelerated the hydration during the wetting phase, while the drying phase strengthened the geopolymer with improved bond structure. This resulted in an increase in short cycles. In the higher cycles, the differences in thermal expansion coefficient and drying shrinkage in the geopolymer structure caused micro-crack formation. However, this situation has been limited due to the compact structure of the geopolymer. While the weight ratios were initially increased due to the wetting effect, they decreased a little later due to micro-cracks. Surface examination of the samples after 50 cycles is shown in Figure 4. According to the visual inspection, no significant damage was observed in the geopolymer concrete specimens, and it was observed that the deterioration remained at the micro-crack levels [16]. The results after the wetting-drying test were in parallel with the pre-test. After 50 cycles, the series using 30% kaolin without fiber and the series using 1.2% tall basalt fiber had 63.18 MPa and 73.39 MPa, respectively, while the UPV results were 4174 m/s and 4298 m/s. The weight changes after 50 cycles were between 0.46% and 1.71%.

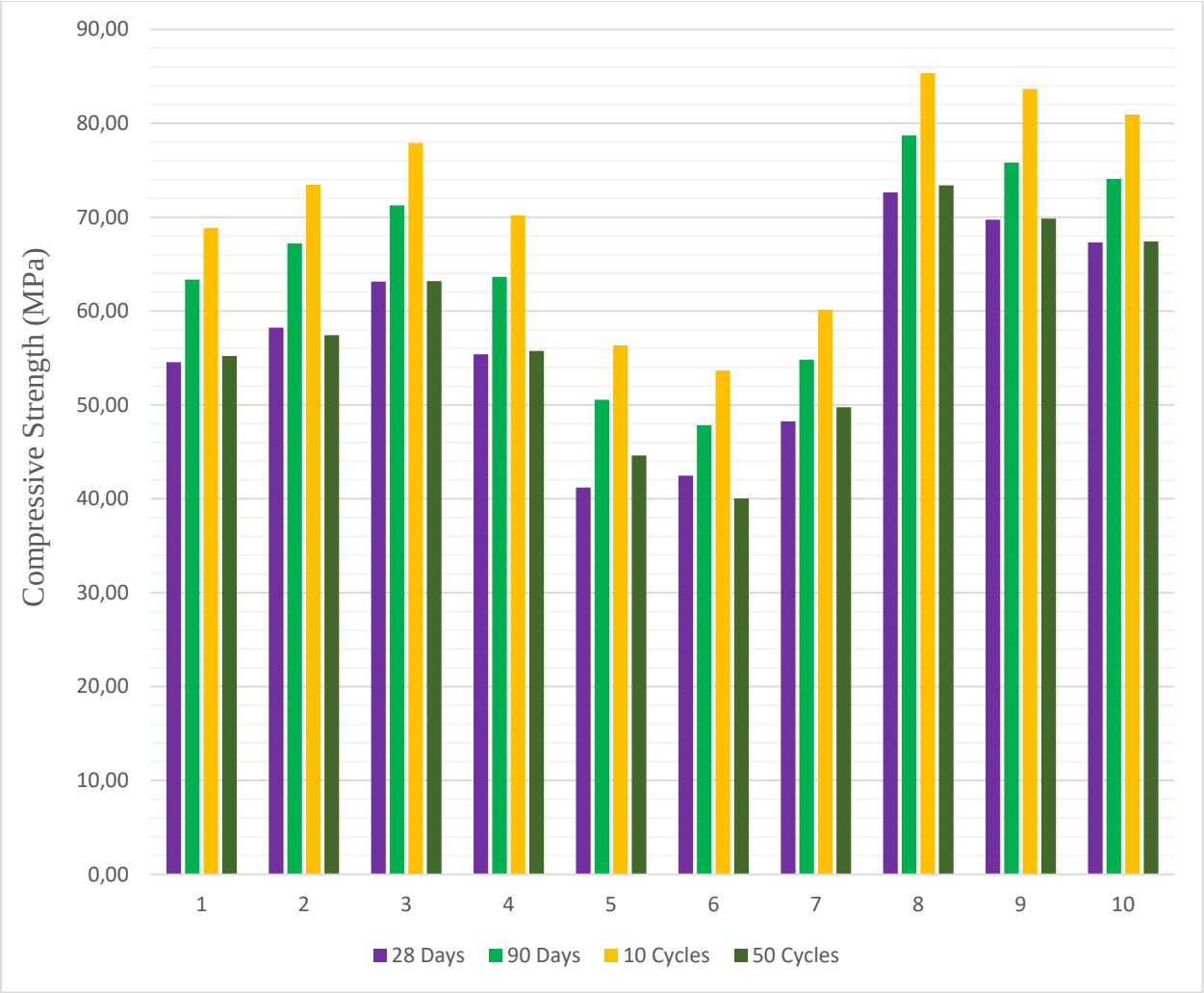


Figure 1. Compressive strength results

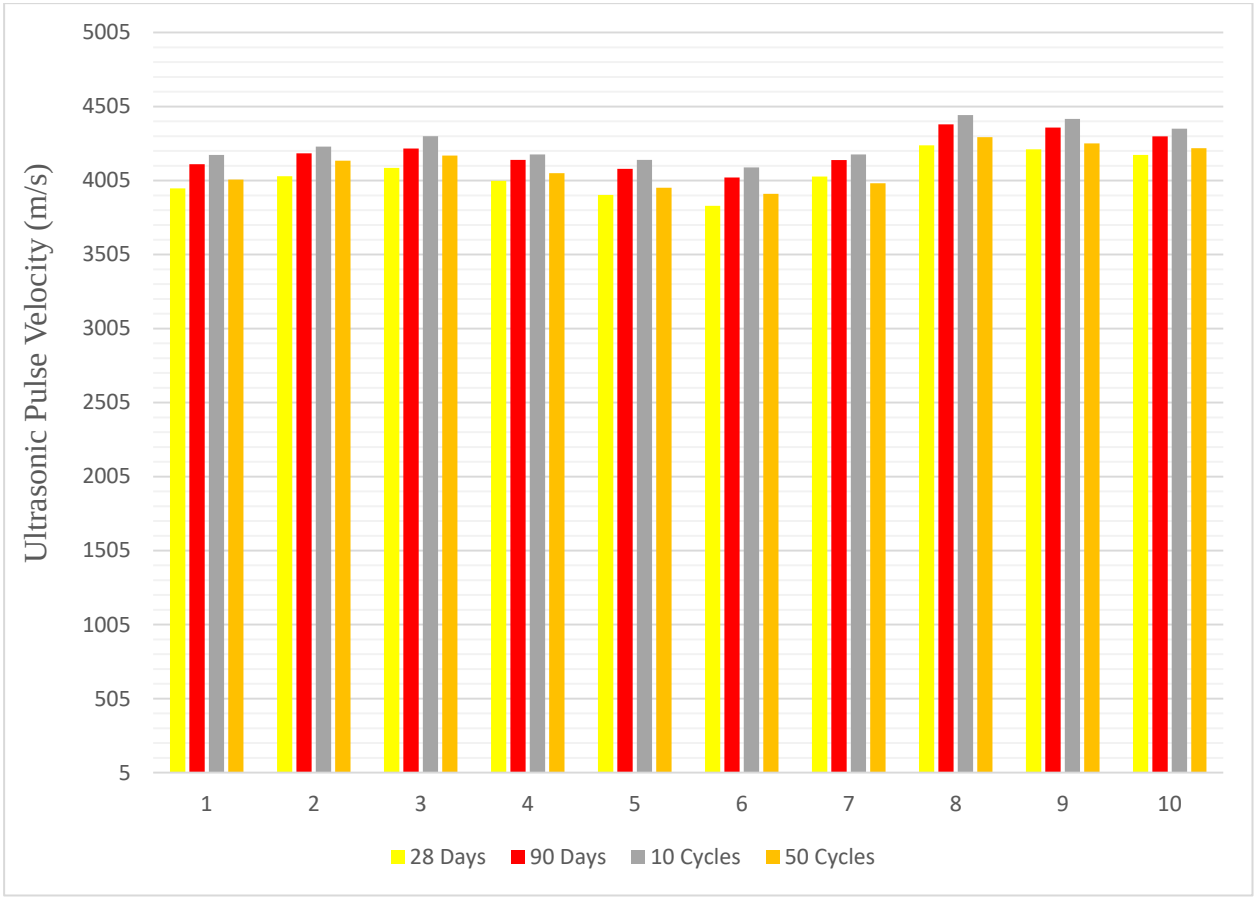


Figure 2. UPV results

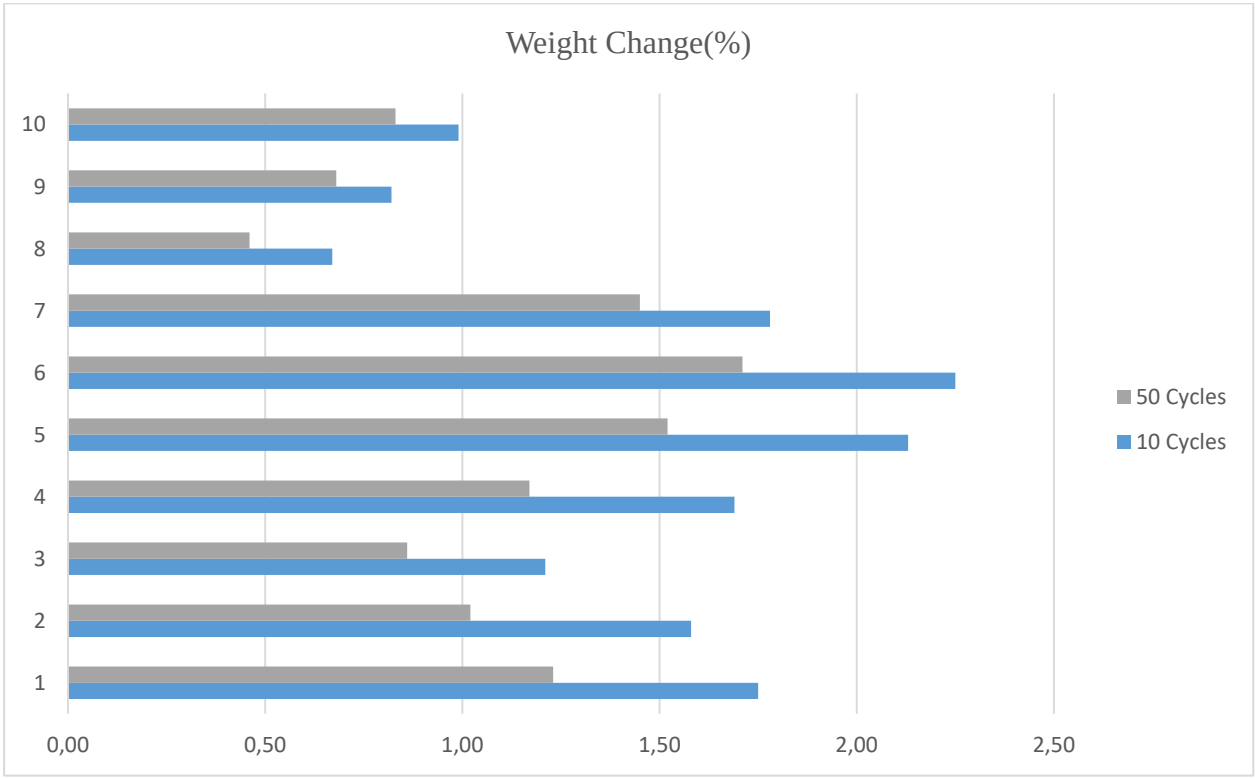


Figure 3. Weight-change results



Figure 4. Visual inspection after the wetting-drying test

4. CONCLUSIONS

Within the scope of the study, the following results were found according to the compressive strength, UPV and weight properties, and visual inspection of the kaolin-substituted slag-based geopolymer concrete specimens before and after the wetting-drying test.

• Slag created a 3-D silico-aluminate structure network by providing significant N-A-S-H and C-A-S-H production in geopolymer concrete due to its high CaO content. This situation provided an important advantage. However, its high rate of use negatively affected workability. Due to the substitution of kaolin up to 30%, because of its fine particle size and the high percentage of SiO_2 and Al_2O_3, it increased geopolymerization and increased mechanical properties. If it was used at a higher rate, it was affected negatively due to its low reactivity.

• The use of tall basalt fiber up to 1.2% provided long anchoring, limiting the cracks, and positively affected the mechanical properties. If it was used at a higher rate, it had a negative effect on workability and has reduced mechanical properties.

• Before and after the wetting-drying test, the results were parallel. After the wetting-drying test, fluctuations in mechanical properties were observed. Hydration formation with the effect of wetting and formation of a denser structure with the effect of drying in short cycles reflected positively on the results. The differences in thermal expansion coefficient and drying shrinkage caused micro-cracks in the following cycles and negatively affected the mechanical properties. Despite these conditions, the geopolymer concrete series showed significant resistance to the wetting-drying effect.

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