An Analysis of Strength and Some Durability Properties of Concretes with Bauxite Waste Additives

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Abstract

This study explores the analysis of strength and some durability properties of concrete specimens with bauxite additive. Durability properties were analyzed by substituting Bauxite Wastes (BW) for sand in different proportions contributing to the originality of our study in this sense. The percentages of bauxite in the sand form are 0%, 10%, 20%, and 50%. The effects of bauxite waste substitution were evaluated by the strength and durability tests in which concrete was exposed at different age stages. Pressure resistance, abrasion, shrinkage in splitting, ultrasonic sound, capillary water absorption, freeze-thaw, and high-temperature tests at 600-800-1000°C in two different cooling regimes (in water and air) were carried out on the specimens of concrete with varying ages with bauxite waste substitution. In the study, the compressive strengths of different amounts of bauxite waste additives on the 7th, 28th, and 60th days were found to be higher in the range of 6%-41% compared to the R specimen. The concrete specimens with bauxite waste, which were exposed to high temperatures in two different cooling regimes, in water and air, revealed a better performance than the R specimen. Therefore, in the study, it was found that the use of concrete with bauxite waste additive was possible with sand substitution and that the concrete specimens with bauxite waste improved the strength and some durability properties.

Keywords: Bauxite waste • Concrete strength • Durability • High temperature

Introduction

Concrete is a building material consisting of granular structures that can be obtained with mixtures such as cement, aggregate, and water, which are used for various purposes in many different areas from bridges to buildings, from skyscrapers to tunnels today [1,2]. Concrete, which is the most suitable material to meet the housing needs of the rapidly increasing population, is one of the most principal factors in the implementation of environmental balance, economy, and efficient application of natural resource models. The rapid development of the construction industry in the world and our country has led to the search for alternative waste materials to replace natural sand, which constitutes 35% of the concrete capacity [3-5]. The uptake of alternative waste materials instead of sand not only contributes to the circular economy but also is instrumental in fostering sustainable progress. Besides, it can enhance the sustainability of concrete by ensuring the use of waste by-products and also by controlling and reducing the use of valuable/productive land allocated for the storage of these wastes [6]. The exponential use of non-renewable resources in the construction sector with the increasing number of projects compels us to consider the concept of sustainability in this sector together with the developments in technology and industry in the coming years [7,8]. Hence, using three definitions of sustainable development (environment, equity, and economy) in this regard, the aim should be to take efficiency as a basis in the use of the resources at disposal, to prevent waste, to control energy use, and to transfer resources to future generations [9,10].

Generally, long service life, high durability against internal and external effects is among the desired features for any produced concrete structure. We can cluster the factors affecting the durability of concrete into three categories: physical: freeze-thaw, high temperature, chemical: alkaline silica reaction, corrosion, mechanical effects: abrasion-cavitation, carbonation, etc. [11]. The effectiveness of the materials used in concrete mixtures depends on the high resistance and durability performance against these possible effects that the concrete will undergo [12-14]. Namely, the performance of concrete against strength and durability problems is related to the material properties in the mixture, its design, and the environmental conditions. Concrete exposed to different deterioration effects may cause some strength and durability problems during service life [15,16]. The freeze-thaw is another crucial durability problem in cold climates. In the freeze-thaw effect, water present in the capillary cavities in concrete increases its volume by 9% due to the decline in temperature and turns it into an ice mass. Damage caused by freeze-thaw effects expands, and ice water causes stresses in concrete, and ice layers formed on its surface cause cracks [17-19]. In the literature regarding the measures to be taken against the freeze-thaw effect, there are studies on the use of some industrial wastes in concrete instead of fine aggregate. Yüksek and Bilir investigated the resistance of concrete against the freeze-thaw by replacing the industrial by-products with base ash and blast furnace slag from the fine aggregate. The results indicated that concretes with base ash and blast furnace slag revealed a convenient performance against the freeze-thaw effect [20]. Penetration and diffusion coefficient are other significant constituents affecting the durability performance of concrete owing to environmental impacts [21-24].

In concrete durability, chemical reactions take place with the penetration of harmful liquids into concrete, and the porosity of the concrete increases, and capillary cavities and harmful liquids cause it to soften and thus its strength to decrease [25-26]. It is known that mineral additives improve the permeability structure of concrete thanks to their properties by decreasing the capillary cavity ratio in concrete structure [27-29]. Notwithstanding, fire, which is another durability problem, creates serious complications for concrete and its elements. Even when there is no life-threatening hazard as a result of fire, structural elements experience a loss of strength and a shortening of service life. When concrete is exposed to high temperatures, cracks occur as a result of internal stresses [30], the vapor pressure in the capillary cavity increases [31], and it causes incrustation in the concrete [32]. Researchers found that the cement matrix decomposed and dehydration process started at 105°C, [33-34], micro cracks were formed at 300-400°C [35], the CSH gels decomposed at 500-600°C and concrete elements above 800°C generally lost strength and weight [33,36]. In the analyses made, it is stated that especially in recent years, the use of mineral additives such as blast furnace slag [36,37,39], fly ash [38-40], silica fume [41-43] improves the strength performance of concretes exposed to high-temperature effects. In addition, researchers ascertained that different cooling regimes (in air and water) have an effect on the strength of concrete after high temperature [42,44,45]. Damage of concrete because of mechanical effects is another physical durability problem [46]. Furthermore, type of aggregate, material mixture ratio, use of mineral additives, and fiber content are among the primary factors in the abrasion resistance of concrete [47,48]. According to the studies conducted in this area, the compressive strength and abrasion resistance values of the concrete are interrelated, and the concretes with high compressive strength values also exhibit high abrasion resistance [49-51].

The bauxite waste used in the study is a by-product material containing insoluble sodium aluminum silicate, iron, and titanium oxides, obtained by the process developed and patented by J. K. Bayer in 1887. The Bayer process, which provides the highest alumina production, is commonly utilized around the world. With this process, iron Fe_2O_3 waste does not dissolve in the aluminum production, and the color it emits has enabled the bauxite waste to be called red mud [52]. According to the researchers [53-54], 0.3-2.5 tons of bauxite-bearing materials is obtained from each ton of alumina processed in the production with the Bayer process. Due to the application of aluminum in a wide range of areas with its lightweight and high strength property, it is among the essential engineering materials today. It is worth mentioning that aluminum with such wide area of use will generate significant industrial waste with increasing demands. For instance, Seydişehir Eti Aluminum plant in Konya processes 460,000 tons of bauxite annually. As a result of the production, there are around 3.5-4 million tons of waste in the facility [55]. The storage of bauxite waste is both uneconomical and creates numerous environmental hazards [56]. When the management plans of waste materials are reviewed, the use of waste products constitutes the most significant step of the waste management process [57]. Therefore, utilizing this waste product and using it in concrete production will save time and cost in terms of compulsory landfill usage, reduction of energy consumption. Consequently, production costs will decrease and the pollutant effect of waste material on the environment will be diminished [58-59].

It is well-known in the literature that wastes such as blast furnace slag, glass plate dust, ceramic, silica fume from different industrial wastes are substituted for fine aggregate in concrete [60-65]. Moreover, researchers examined the effects on the strength properties of concrete by replacing the bauxite waste from sand and concluded that the bauxite waste increased the strength in concrete positively with obtained experimental data [66]. Zhang et al. investigated the effects of protective concretes on impact resistance against high-velocity bullets by using bauxite as sand and granite as coarse aggregate. With their experimental results, they affirmed that bauxite-sand-added concretes had superior impact resistance properties [67]. In another study, bauxite waste was replaced by cement at a rate of 1-20% and it was observed that the setting time of concrete was shortened, and cracking and deformations in concrete decreased [68]. Raj and all determined the strength and durability properties of concrete by using 0%-14% w/b ratio from cement and 0.33-0.36-0.38-0.40 ratio of bauxite and with the results obtained; they stated that the steel embedded in the concrete increased the corrosion resistance. [69]. Ahmed et al. stated that the samples produced with Nano-SiO_2 added by changing the oxides of red mud increased the compressive strength and contributed to the workability [70]. In yet another study, Wang et al. determined the methods of using red mud and determined the methods to make the most use of this mud for future studies [71]. In addition, Rajabi et al. investigated the relationship between two-stage concrete and conventional concrete with empirical formulas, and stated that mechanical values could be determined by non-destructive experiments and production cost and time would be reduced [72]. Accordingly, this study caters to the use of Bauxite Waste (BW) material in the production of concrete specimens. Besides, it aims to examine the effects of bauxite waste to be substituted for fine aggregate in concrete on strength and durability performances. Bauxite waste was used as 10%, 20%, and 50% instead of fine aggregate. Analysis of performance effects of concrete specimens produced with bauxite wastes were carried out with compressive strength, tensile strength in splitting, abrasion resistance, freeze-thaw resistance tests, and their strength and durability properties were also analyzed with different cooling regimes at 600-800 and 1000°C.

Materials and Methods

Materials

CEM I 42.5 cement was utilized in the study following TS 197-1 [73] standard. Bauxite Waste (BW) is a material released as a result of the Bayer process and aluminum production process, which is also called red mud due to its iron content. Bauxite waste was supplied from the Seydişehir Eti Maden Aluminum factory in Konya. SEM image of bauxite waste is given in Figure 1 its physical, chemical, mineralogical properties are given in Tables 1 and 2 [74-76]. 0-4 mm crushed sand was used as fine aggregate while crushed aggregate was used as coarse aggregate. The properties of fine and coarse aggregate are given in Table 3.

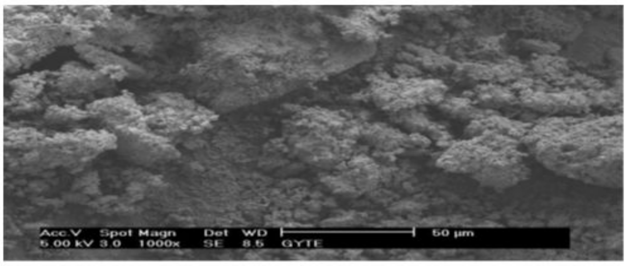

Figure 1. SEM image of bauxite waste.

Table 1. Physical and chemical properties of bauxite

Parameter	Bauxite waste
Color	Red
Density (kg/m^3)	1310.46
Pore volume (cc/g)	0.019
Specific Surface Area (m^2/g)	13.765
pH	10.58
Electrical Conductivity (dS/m)	8.60
Total Organic Carbon (mg/kg)	10205
Cs-134 (Bq/kg)	<4.4
Cs-137 (Bq/kg)	<5.7
Ra-226 (Bq/kg)	128.1 ± 3.2
Th-232 (Bq/kg)	357.4 ± 9.6
K-40 (Bq/kg)	110.4 ± 22.4

Table 2: Chemical components of bauxite waste.

Oxide	%
Al_2O_3	21.995
As_2O_3	0.026
CaO	4.452
Ce_2O_3	0.078
Cl	0.059
Cr_2O_3	0.108

Fe_2O_3	36.422
Ga_2O_3	0.005
K_2O	0.52
MgO	0.293
MnO_2	0.029
Na_2O	12.532
Nb_2O_5	0.009
NiO	0.055
P_2O_5	0.021
PbO	0.014
SO_3	5.486
SiO_2	13.254
SrO	0.005
ThO_2	0.009
TiO_2	4.497
Y_2O_3	0.021
ZrO_2	0.11

Table 3. Physical properties of fine and coarse aggregate.

Property	Sand (0-4 mm)	Crushed stone (4-16 mm)
Specific gravity	2.71	2.80
Water absorption (%)	1.95	1.05
Abrasion rate (%)	-	20.4

Methods

Preparation of concrete and specimens

The concrete design was made following the TS EN 802 [77] standard and the mixing ratios are given in Table 4. Instead of fine aggregate, bauxite waste was used at 10%, 20%, and 50% and named according to the number of additives. In addition, concrete samples were produced in accordance with the EN 12350-7 [78] standard on the amount of entrained air of fresh concrete. The contribution of the fresh concrete to the amount of entrained air is to increase the workability of the fresh concrete. The entrained air bubbles take role as an air cushion between the solid particles and increase the workability of the concrete by reducing the friction between them [79].

Compressive strength

Compressive strength was made following TS EN 12390-3 [80] standard. In the experimental study, 100 × 100 × 100 mm cubic specimens were used. All specimens produced were cured in the tap water pool at 21-23°C for 7, 28, and 60 days.

Splitting tensile strength

Splitting tensile strength values of concrete is of great importance in terms of providing information about the formation of crack analysis that may occur in the structure and its elements. It is also crucial to prevent the formation of cracks, especially in mass concretes, airport concretes, concrete road constructions, etc. [81]. Splitting tensile strength was made following TS EN 12390-6 [82] standard. 150 × 300 mm cylindrical specimens produced for the experiment were kept in the cure pool at 21-23°C for 7, 28 and 60 days.

Abrasion resistance

Abrasion loss occurs as a result of friction of concrete surfaces with another substance under the effect of an abrasive substance. Abrasion is a long-lasting physical and mechanical occurrence but is particularly critical for the road safety of vehicles in motion [83]. In this study, specimens of 71 × 71 × 71 mm were produced following the TS EN 2824 standard to determine the abrasion resistance of concrete, which is a composite material [84].

The freeze-thaw effect

The freeze-thaw strength of the concrete specimens with bauxite additive was made under the ASTM C666-97 [85] standard. All specimens of 28 days were exposed to freeze-thaw cycles between -20°C and +20°C. At the end of the freeze-thaw cycle, the compressive strength and the resulting mass losses of the concrete specimens were determined.

The high temperature effects

To determine the resistance of the 28-days specimens against the effects of high temperatures, the concretes were kept in an electric furnace at 600-800 and 1000°C for 1 hour. In the test method in which two different cooling regimes were used, the specimens exposed to the air-cooling regime were allowed to cool under room conditions, while the specimens with the water-cooling regime were immersed in the water tank to cool. Concrete specimens were documented by measuring their compressive strength after high temperature and UPV values.

Ultrasonic penetration rate test (UPV)

It is known that there is a certain relationship between ultrasonic velocity and concrete density. Compressive strength of concretes with high density is also expected to be high. The amount of cavity is one of the most key parameters affecting concrete strength [86]. Decreasing the amount of cavity in concrete rises the ultrasonic sound penetration rate coefficient. Ultrasonic sound penetration tests were applied to 28-day-old specimens under ASTM C 597 standards [87].

Capillary water absorption

Capillary water permeability rates of concrete specimens were calculated according to Darcy's law. The specimens whose capillary water absorption rate to be determined were kept in the oven at ± 105°C for 24 hours and the oven-dry weights of the specimens were weighed. Later, the side surfaces of all specimens were covered with silicone at a height of 5 mm. Following TS EN 4045 [88] standards, specimens of 100 mm immersed in water. Then their weight gains were measured at the end of 5, 10, 30, 60, 240, and 1440 minutes, and the amount of water absorbed by the specimens was determined.

Table 4: Mixture proportions (kg/m^3).

Specimen	Cement	Water	Coarse aggregate	Sand	
				River Sand	Bauxite waste
R	400	210	1200	450	-
BW10	400	210	1200	405	45

BW20	400	210	1200	360	90
BW50	400	210	1200	225	225

Results and Discussion

Compressive strength

Compressive strength values of 7, 28, and 60-day concrete are given in Figure 2.

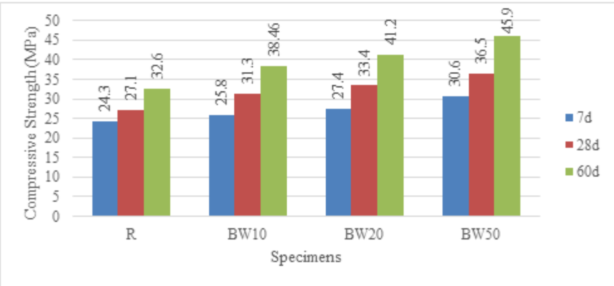

Figure 2. Compressive strength of bauxite-added concrete at 7, 28 and 60 days.

According to the 7 days compressive strength values, it is stated that the compressive strength values of the BW added specimens were higher by 6%, 13%, and 26%, respectively, compared to the reference specimen. It was determined that the BW added specimens were 16%, 22%, and 36% respectively in the 28 days results, and the BW added specimens were 18%, 26%, and 41%, respectively, in the 60-day results. While the R specimen shows the lowest compressive strength value on different days in the study, all specimens with additives have a higher compressive strength than the reference specimen, and it is known that the specimen with the highest compressive strength value is BW50 with 42.9 MPa at the end of 60 days. The fact that the specimens with bauxite wastes with fine aggregates have higher compressive strength values compared to the reference concrete can be explained by the presence of high levels of Al_2O_3 and Fe_2O_3 and the effect of calcium oxide, which plays an active role in the increase of strength [89-90]. In addition, the increase in the content of bauxite waste used in concrete by substituting it from fine aggregate contributes positively to the increase in strength as well as the increase in density. A strong positive correlation between concrete compressive strength and density is shown in Figure 3 where the correlation coefficient is specified. The result of the correlation coefficient R_2=0.9954 also proves this interpretation. As a result, the increase in the density of specimens with bauxite waste yields higher results in concrete compressive strength [91-92].

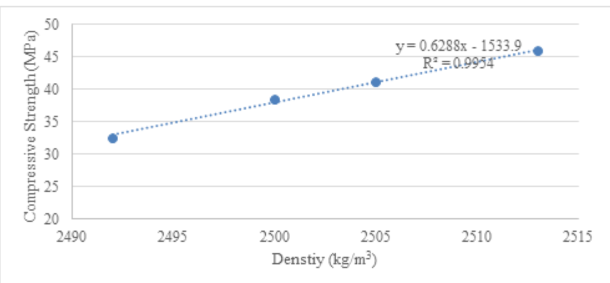

Figure 3. Compressive strength-density relationship of specimens with bauxite waste.

Tensile splitting strength test

The compressive strength values of 7, 28, and 60 days concrete are given in Figure 4.

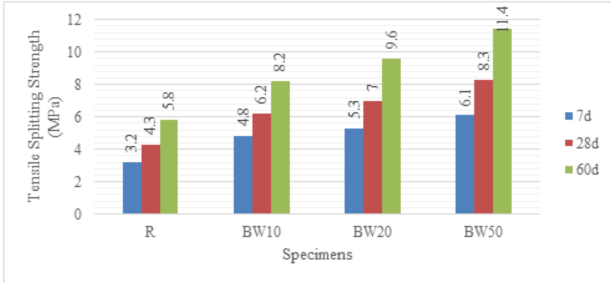

Figure 4. Tensile strength of bauxite-added concretes on the 7th, 28th and 60th days.

According to the 7 days splitting tensile strength values, it is stated that the tensile strength values of the BW added specimens are higher by 5%, 12%, and 27% respectively, compared to the reference specimen. In the results of 28 days, it was determined that the BW added specimens were 17%, 21%, and 36% respectively, and the BW added specimens were found to be 19%, 27%, and 42%, respectively, in the 60 days results. Tensile values in the 7, 28 and 60 days splitting results show the lowest value of the R specimen, and the specimen with the highest splitting strength value is the specimen coded BW50 with 8.23 MPa at the end of 60 days. The high values of the specimens with bauxite in the splitting strength test can be explained by the high elasticity modulus of the bauxite aggregate and its high strength [93-94]. Splitting tensile strength values obtained at the same time are related to the compressive strength values given in Figure 2. This observation is supported by the correlation coefficient R_2=0.9981 obtained in Figure 5.

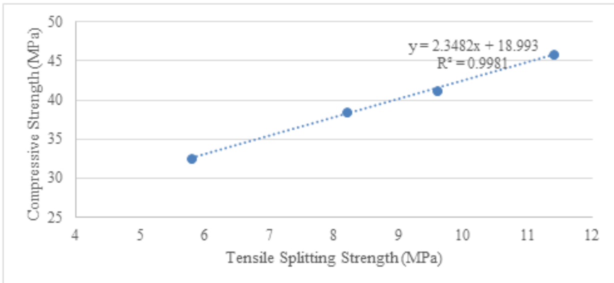

Figure 5. Compressive strength of specimens with bauxite waste and tensile strength in.

Capillary water absorption

The capillary water absorption coefficients of the specimens for 28 days are given in Figure 6.

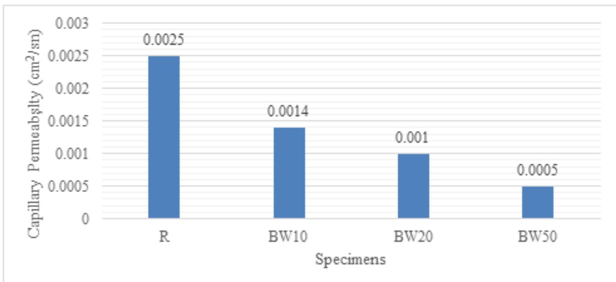

Figure 6. Capillary permeability coefficients of BW specimens.

When the test results are examined, it is seen that the reference specimen has the highest water absorption capacity. The water absorption coefficient of the specimens with BW additive decreases depending on the increase in the amount of additive. It is possible to explain this situation with the tighter non-porous structure of the BW contribution and the high value of the correlation number R2=0.9515 determined in Figure 7. As seen in Figure 6, the specimen with the least water absorption coefficient is the one with the code BW50. The capillarity coefficient of the specimen with 10% BW additive was found to be 44% lower than the R specimen, 60% for the 20% BW added specimen and 80% for the specimen with 50% BW. As a result, it is concluded that the type and the additive ratio of the material substituted as fine aggregate has an important effect in determining the capillary water absorption coefficient.

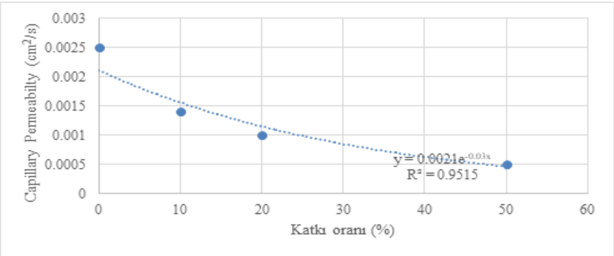

Figure 7. Relationship between capillary water absorption coefficient and the number of specimens with bauxite additive.

Abrasion resistance

The 28 days abrasion test results are given in Figure 8.

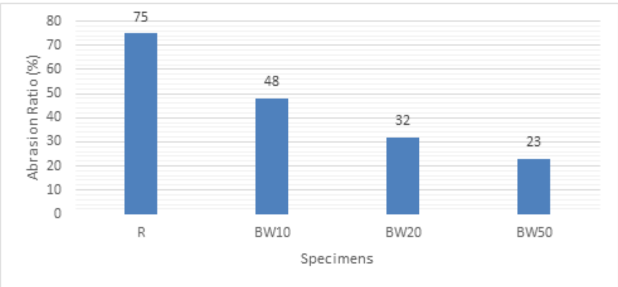

Figure 8. Abrasion ratio of BW specimens.

The results show that the abrasion resistance of the R specimen without additives is the lowest. When the values of the BW added specimens are examined, the rate of abrasion loss decreases as the additive rate increases. The abrasion losses of the specimens with BW10, BW20, and BW50 additives are 23%, 32%, and 48%, respectively. The high abrasion resistance of the BW added specimens can be explained by the hard structure of the bauxite aggregate and its strength-enhancing effect [93]. At the same time, it is indicated by the correlation coefficient obtained in Figure 9 that there is a serious relationship between capillary water absorption coefficients and abrasion losses. The high R_2=0.9997 correlation number reveals that concretes with high capillary water absorption coefficient also have higher abrasion losses.

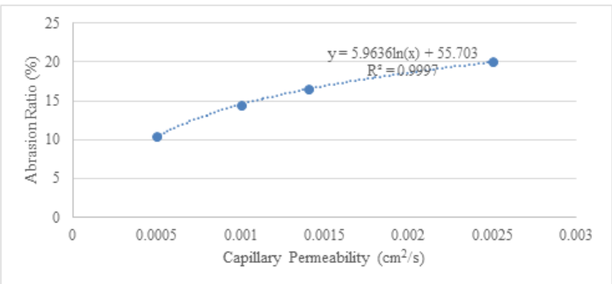

Figure 9. Abrasion ratio–Capillary water absorption relationship.

Ultrasound speed test

Ultrasonic velocity values of specimens with bauxite additive on the 7th, 28th, and 60th days are given in Table 5. Based on the compressive strength values given in Figure 2, it is observed that bauxite waste substitution with sand has reduced the cavity ratio in concrete. Besides, it is clear that there is a serious relationship between the cavity structure and the compressive strength with the higher R_2 correlation number obtained in Figure 10.

Table 5. Ultrasound speed test (m/s).

Specimen	7 d	28 d	60 d
R	4680	5230	5435
BW10	5388	5808	5891
BW20	5525	5835	5930
BW50	5630	5980	6110

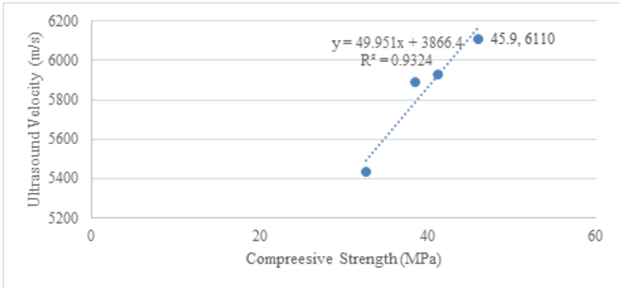

Figure 10. Ultrasound velocity-Compressive strength relationship.

Compressive strengths after freeze-thaw

Compressive strengths obtained after freezing-thaw are given in Figure 11.

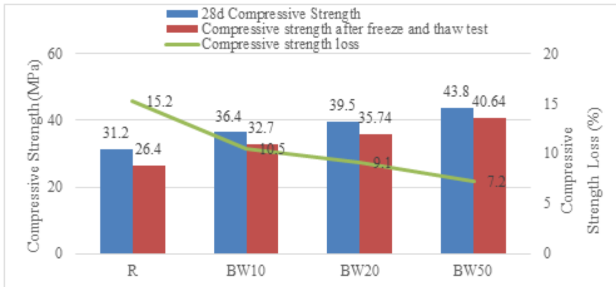

Figure 11. Compressive strength after freeze-thaw test.

When the values are examined, the R specimen had 15.2% pressure loss, BW10 10.5%, BW20 9.1%, and BW50 7.2%, respectively. According to the pressure losses obtained, the R specimen shows the highest loss. It is seen that all specimens with BW additives contribute positively to the freeze-thaw resistance of concrete. The freeze-thaw strength depends on the factors of concrete's cavity structure, saturation, s/c ratio, etc. In the previous studies, the use of mineral additives positively contributes to the mechanical and durability properties of concrete [94]. The BW additive used in the study also contributes positively to the improvement of much strength and some durability properties of concrete.

Compressive strength after high temperature

At the end of 28 days, two different cooling regimes were applied to the specimens under the effect of 600-800 and 1000°C high temperature and the values obtained from the specimens are given in Table 6.

The comparative results of the compressive strength values with the R specimen are also given in Figure 12. When the results are evaluated according to the type of cooling after high temperature, in the water-cooling regime at 600°C, the R specimen had 28%, BW10 15%, BW20 13%, and BW50 10% pressure loss. At 600°C, the R specimen had the lowest strength and the BW50 added specimen had the highest strength. At 800° C, the R specimen had 62%, BW10 48%, BW20 41% and BW50

32% pressure loss. At 800°C, the R specimen showed the lowest resistance and the highest strength was the specimen with BW50. After the water-cooling regime at 1000°C, all specimens were damaged and the value could not be obtained. In the air-cooling regime, at 600°C, the R specimen had 21%, BW10 18%, BW20 16%, and BW50 12% pressure loss. At 600°C, the R specimen had the lowest strength and the BW50 added specimen had the highest strength. At 800°C, R specimen had 51%, BW10 43%, BW20 35% and BW50 29% pressure loss. At 800°C, the R specimen had the lowest strength and the BW50 added specimen had the highest strength. At 1000°C, the R specimen had 72%, BW10 60%, BW20 52% and BW50 48% pressure loss. At 1000°C, the R specimen had the lowest strength and the BW50 added specimen had the highest strength.

Considering the test results of the specimens cooled after high temperature using water and air cooling regimes, the strength of the specimens left to cool in the air cooling at 600°C was found to be lower than the specimens using the water cooling regime. In the results at 800-1000°C, specimens cooled in water give lower results than the specimens left to cool in the air environment. All the specimens in the water-cooling regime at 1000°C were damaged and no result was obtained. The fact that specimens left to cool in the air at 600°C after high temperatures show a lower pressure value than specimens cooled in water can be explained by the volume expansion that occurs in the conversion of $CaCO_3$ to CaO during the longer cooling times of the specimens in the air environment [95]. It is possible to say that specimens that are left to cool in water at 800-1000°C have lower resistance values than specimens left in the air environment. Moreover, the reason why values couldn't be obtained at 1000°C can be explained by the thermal shock effect the specimens went through in a short period of time, thus yielding to low strength [96-98].

Table 6. Residual compressive strength results at 28 days.

Specimen	25°C	Water Cooling			Air Cooling		
		600°C	800°C	1000°C	600°C	800°C	1000°C
R	31.2	24.64	11.85	Completely destroyed	22.46	15.3	8.73
BW10	36.4	27.3	18.92		29.84	20.74	14.56
BW20	39.5	30.81	23.3		33.18	25.67	18.96
BW50	43.8	37.23	29.78		38.54	31.09	22.76

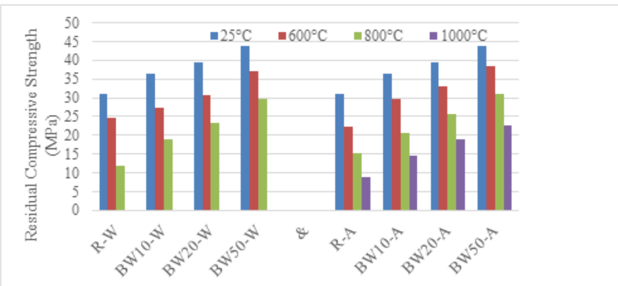

Figure 12. Residual compressive strength.

UPV results after high temperature

UPV results before and after exposure to high temperature at the end of 28 days is given in Figure 13. UPV values before high temperature give values between 5230-5980 m/s. UPV results of the same specimens cooled in water regime after 600°C high temperature are between 3412-4400 m/s. UPV results of specimens cooled in air environment are between 3610-4510 m/s. UPV results of specimens cooled in water at 800 °C are between 2000-2784 m/s, and UPV results of specimens cooled in the air are between 2154-2961 m/s. At 1000°C, the specimens cooled in water were damaged by the thermal shock effect [96], therefore the UPV results of the specimens cooled only in the air were determined to be between 1300-2640 m/s. It is known that there is a serious relationship between UPV results and strength results, porosity, and density of concrete [99]. The test results obtained from specimens with bauxite additives are also similar to the results of previous studies.

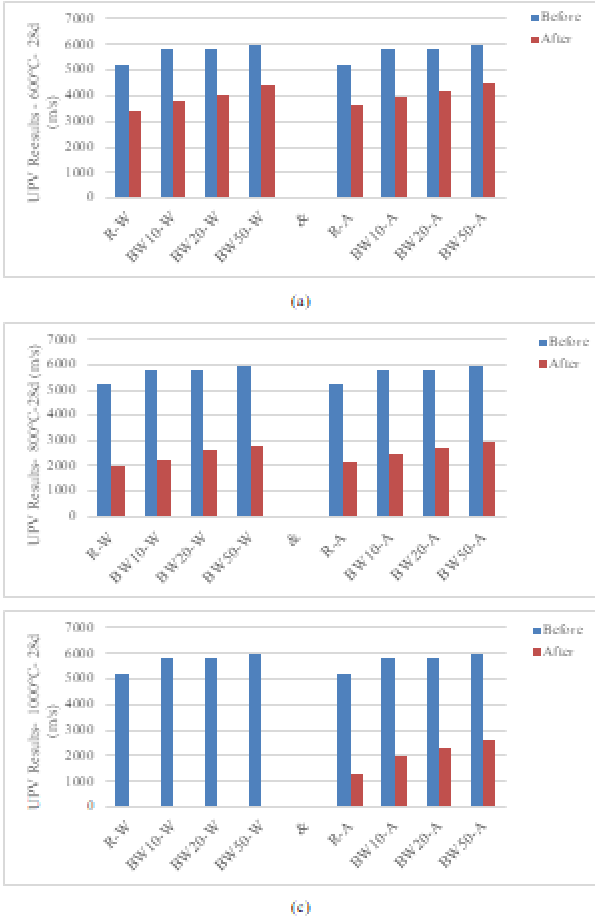

Figure 13. 28-Day UPV test results (a) 600°C (b) 800°C (c) 1000°C.

Conclusion

Investigating the possibility of using bauxite waste as an alternative in meeting the need for fine aggregate in concrete production, the following conclusions have been drawn.

1. In the study, the use of bauxite waste by substituting fine aggregate caused an increase in concrete density. The specimen with the highest density was the specimen with BW50 additive with 2513 kg/m^3.

2. In compressive strength, as the ratio of using bauxite waste instead of fine aggregate increases, pressure strength increases. In the study, the highest compressive strength value was obtained from BW50 added specimen with 42.9 MPa.

3. In the tensile splitting strength test, the tensile values in the 7, 28, and 60 days splitting results show that the R specimen had the lowest value, the specimen coded BW50 with 8.23 MPa had the highest tensile strength value at the end of 60 days. Its relation with compressive strength was also indicated with the correlation number R_2=0.9981.

4. In capillary water absorption, it is seen that the reference specimen had the highest water absorption capacity with 0.0025 cm^2/sec. The water absorption coefficient of the specimens with BW additive decreased depending on the increase in the amount of additive. It is possible to explain this situation with the tighter non-porous structure of the BW

contribution with the high value of the correlation number determined as R_2=0.9515.

5. In abrasion resistance, in the results obtained after 28 days, it is seen that the abrasion resistance of the pure R specimen is the lowest with 75%. When the values of the specimens with BW additives are examined, it is stated that the abrasion loss rate decreases as the additive rate increases, the abrasion losses of the BW10, BW20, and BW50 added specimens are 23%, 32%, and 48%, respectively. Concretes with high capillary water absorption coefficient also have higher abrasion losses, which is indicated by the high R_2=0.9997 correlation number.

6. In the ultrasound speed test, the 7 days ultrasonic velocity values of the R specimen without additive and the bauxite waste-added specimens are between 4680-5630 m/s. 28 days velocity values are between 5230-5980 m/s and 60-day ultrasonic velocity values are between 5435-6110 m/s. The effect of bauxite waste used by substituting sand to reduce the cavity ratio in concrete is explained by the high value of R_2=0.9324 correlation number. This indicates the relationship between ultrasonic sound and compressive strength.

7. In compressive strengths after freeze-thaw, the R specimen had 15.2%, BW10 10.5%, BW20 9.1%, and BW50 7.2% pressure loss. According to the pressure losses obtained, the R specimen shows the highest loss. BW50 added specimen showed the highest freeze-thaw resistance with 40.64 MPa.

8. Compressive strength after the high temperature at 600°C in water cooling regime, the R specimen showed the lowest compressive strength with 24.64 MPa, and the highest strength was shown with the BW50 added specimen with 37.23 MPa. At 800°C in water cooling regime, the R specimen showed the lowest compressive strength with 11.85 MPa while the highest strength showed the BW50 added specimen with 29.78 MPa. Since all specimens were damaged at 1000°C, values could not be obtained. At 600°C in the air-cooling regime, the R specimen showed the lowest compressive strength with 22.46 MPa, and the highest strength was shown with BW50 added specimen with 38.54 MPa. At 800 °C in air cooling regime, the R specimen showed the lowest compressive strength with 15.30 MPa and the highest strength was shown with BW50 additive with 31.09 MPa. At 1000°C in air cooling regime, the R specimen showed the lowest compressive strength with 8.73 MPa and BW50 added specimen had the highest strength with 22.76 MPa.

9. Considering the effect of cooling regimes, specimens left for cooling in a water environment at 600°C have a better performance than specimens left for cooling in an air environment, and specimens exposed to a cooling regime in the air at 800°C and 1000°C give better results than specimens with the cooling regime in a water environment.

Credit Authorship Contribution Statement

Ela B. Gorur Avsaroglu: Methodology, Investigation, Recources, Project administration, Writing-review and editing.

Mustafa Eken: Methodology, Investigation, Recources, Project administration, Writing-review and editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Quek ST, et al. Development of functionally-graded cementitious panel against high-velocity small projectile impact. *Int J Impact Eng.* 37.8 (2010): 928-941.
2. Singha G, et al. Study of Granulated Blast Furnace Slag as Fine Aggregates in Concrete for Sustainable World Conference on Technology, Innovation and Entrepreneurship Infrastructure. *Procedia Soc Behav Sci.* 195 (2015): 2272-2279.
3. Mundraa S, et al. Crushed rock sand-An economical andecological alternative to natural sand tooptimize concrete mix Engineering and Mate-rial Sciences. *Perspect Sci.* 8 (2016): 345-347.
4. Cimen S, et al. Reuse of recycled aggregates in the construction industry. *J Sustainable Eng Practices Technol Develop.* 1.1 (2018): 44-54.
5. Aggarwal Y, et al. Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates. *Constr Build Mater.* 54 (2014): 210–223.
6. Muthusamy K, et al. Coal bottom ash as sand replacement in concrete: A review. *Constr Build Mater*. 236 (2020): 117507.
7. Opaku A. Biodiversity and the built environment: implications for the sustainable development goals (SDGs). *Resour Conserv Recycl.* 141 (2019): 1–7.
8. Danso H. Identification of Key Indicators for Sustainable Construction Materials. *Adv Mater Sci Eng.* (2018): 1-7.
9. Ozden EM, et al. How Can Cities Help Achieve the Sustainable Development Goals? *Soc Sci Res.* 7.4 (2018): 255-268.
10. Sakthivel PB, et al. An Innovative Method of Replacing River Sand by Quarry Dust Waste in Concrete for Sustainability. *Int J Sci Eng Res.* 4.5 (2013): 246-249.
11. Binici H, et al. Durability properties of concretesmadewith sand and cement size basalt. *Sustain Mater Technol.* 23 (2020): 00145.
12. Ramachandran VS (2001) Concrete Admixture Handbook. Properties, Science and Technology. (2nd edition), Noyes Publications, New Jersey, USA.
13. Mehta PK. Durability critical issues for the future. *Concr Int.* 19.7 (1997): 69–76.
14. Yuksel I, et al. Durability of concrete incorporating non-ground blast furnace slag and bottomash as fine aggregate. *Build Environ.* 42 (2007): 2651–2659.
15. Binici H, et al. Performance of ground blast furnace slag (GBS) and ground basaltic pumice (GBP) concrete against seawater attack. *Constr Build Mat.* 22.7 (2008): 1515–1526.
16. Neville AM (1995) Properties of Concrete. Wiley, England.
17. Baradan B, et al. (2012) Concrete. Dokuz Eylül University Faculty of Engineering Publications, İzmir, Turkey.
18. Powders TC, et al. (1953) "Theory of volume changes in hardened portland cement pastes during freezing". Thirty-Second Annual Meeting of the Highway Research Board, Washington, USA.
19. Mehta PK, et al. (2006) Concrete: Microstructure, Properties, and Materials. McGraw-Hill, 3rd edition, New York.
20. Yüksel İ, et al. Durability of Concrete Incorporating Non-Ground Blast Furnace Slag and Bottom Ash as Fine Aggregate. *Build Environ.* 42 (2007): 2651-2659.
21. Lu X, et al. Evaluation of concrete permeability by critical voltage. *Cem Concr Res.* 30 (2000): 973–975.
22. Atcin PC. The durability characteristics of high performance concrete: a review. *Cem Concr Compos.* 25 (2003): 409–420.
23. Chang PK, et al. A design consideration for durability of high performance concrete. *Cem Concr Compos.* 23 (2001): 375–380.
24. Zhutovsky S, et al. Effect of internal curing on durability-related properties of high performance concrete. *Cem Concr Res*. 42 (2012): 20–26.
25. Dinakar P, et al. Behaviour of Self Compacting Concrete Using Portland Pozzolana Cement with Different Levels of Fly Ash. *Mater Des.* 46 (2013): 609-616.
26. Mehta PK. Advancements in concrete technology. *Concr Int.* 96.4 (1999): 69-76.
27. Asbridge HA, et al. Effects of metakaolin and the interfacial transition zone on the diffusion of chloride ions through cement mortars. *Cem Concr Res*. 31 (2001): 1567–1572.

28. Valipour M, et al. Comparing a natural pozzolan, zeolite, to metakaolin and silica fume in terms of their effect on the durability characteristics of concrete: A laboratory study. *Const Build Mater*. 41 (2013): 879–888.

29. Gruber KA, et al. Increasing concrete durability with high-reactivity metakaolin. *Cem Concr Compos*. 23 (2001): 479–484.

30. Fu YF, et al. Thermal induced stress and associated cracking in cement-based composite at elevated temperatures-Part II: Thermal cracking around multiple inclusions. *Cem Concr Compos*. 26.2 (2004): 99–111.

31. Abid M, et al. High temperature and residual properties of reactive powder concrete – A review. *Constr Build Mater*. 147 (2017): 339–351.

32. Noumowe AN, et al. Permeability of high-performance concrete subjected to elevated temperature (600C). *Constr Build Mater*. 23.5 (2009): 1855–1861.

33. Arioz O. Effects of elevated temperatures on properties of concrete. *Fire Saf J*. 42.8 (2007): 516–522.

34. Aydın S, et al. Effect of pumice and fly ash incorporation on high temperature resistance of cement based mortars. *Cem Concr Res*. 37 (2007): 988–995.

35. Gavin D, et al. Modelling of deformations of high strength concrete at elevated temperatures. *Mater Struct*. 37.4 (2004): 218–236.

36. Akca AH, et al. Effects of re-curing on microstructure of concrete after high temperature exposure. *Constr Build Mater*. 168 (2018): 431–441.

37. Siddique R, et al. Properties of concrete containing ground granulated blast furnace slag (GGBFS) at elevated temperatures. *Cairo Univ J Adv Res*. 3 (2012): 45–51.

38. Wang W, et al. An investigation on thermal conductivity of fly ash concrete after elevated temperature exposure. *Constr Build Mater*. 148 (2017): 148–157.

39. Yüksel I, et al. Influence of high temperature on the properties of concrete made by industrial by-products as fine aggregate replacement. *Constr Build Mater*. 25.2 (2011): 967–972.

40. Liang X, et al. Development of ultra-high performance concrete with high fire resistance. *Constr Build Mater*. 179 (2018): 400–412.

41. Chan YN, et al. Compressive strength and pore structure of high performance concrete after exposure to high temperature 800C. *Cem Concr Res*. 30 (2000): 247–251.

42. Luo X, et al. Effect of heating and cooling regimes on residual strength and microstructure of normal strength and high-performance concrete. *Cem Concr Res*. 30 (2000): 379–383.

43. Varona FB, et al. Evolution of the bond strength between reinforcing steel fibre reinforced concrete after high temperature exposure. *Constr Build Mater*. 176 (2018): 359–370.

44. Karakoç MB. Effect of cooling regimes on compressive strength of concrete with lightweight aggregate exposed to high temperature. *Constr Build Mater*. 41 (2013): 21–25.

45. Gupta T, et al. Effect of elevated temperature and cooling regimes on mechanical and durability properties of concrete containing waste rubber fiber. *Constr Build Mater*. 137 (2017): 35–45.

46. Eriç M (1994) Building Physics and Materials. Literatür Yayıncılık, Istanbul.

47. Yen T, et al. Influence of class F fly ash on the abrasion–erosion resistance of high-strength concrete. *Constr Build Mater*. 21 (2007): 458-463.

48. Krishna RS, et al. Abrasion resistance and mechanical properties of Roller Compacted Concrete with GGBS. *Constr Build Mater*. 114 (2016): 925-933.

49. Li H, et al. Abrasion resistance of concrete containing nano-particles for pavement. *Wear*. 260 (2006): 1262-1266.

50. Siddique R. Compressive strength, water absorption, sorptivity, abrasion resistance and permeability of self-compacting concrete containing coal bottom ash. *Constr Build Mater*. 47 (2013): 1444-1450.

51. He Z, et al. Influence and mechanism of micro/nano-mineral admixtures on the abrasion resistance of concrete. *Constr Build Mater*. 197 (2019): 91-98.

52. Aksu S (2001) Solubility of Red Mud Components in Hydrochloric Acid Solution. Master Thesis, SAU Institute of Science, Sakarya, Turkey.

53. Snars KE, et al. The liming effect of bauxite processing residue (red mud) on sandy soils. *Aust J Soil Res*. 42.3 (2004): 321-328.

54. Tosun O (2010) Characterization of Liquid Phase Obtained from Pyrolysis of Kütahya Seyitömer Bituminous Shale Mixture with Low Density Polyethylene (Dype) at Different Temperatures. Master Thesis, Ankara University, Ankara, Turkey.

55. Mus S, et al. (2015) Aluminum Plant Red Mud Waste Dam Engineering and Environmental Geology Istanbul Technıcal Unıversıty Instıtute Of Scıences Master's Thesıs.

56. Akıncı A (2004) Effect of Additives on Structure and Properties in Polymer Matrix Composites, PhD Thesis, SAU Institute of Science, Metallurgy and Materials Engineering, Sakarya.

57. Tınmaz E, et al. An application example for red sludge recovery: solidification/stabilization. 1st International Engineering Architecture and Design Congress, Kocaeli, Turkey. 2015:13-14.

58. Yegen A (2002) Adsorption of Phosphate in Water Using Chemical Waste Materials, Master Thesis, SAU Institute of Science, Sakarya, Turkey.

59. Cachim P (2018) Waste and supplementary cementitious materials in concrete: characterisation, properties and applications. (1st Edition) Woodhead Publishing, Turkey.

60. Mageswari M, et al. The Use of Sheet Glass Powder as Fine Aggregate Replacement in Concrete. *Open Civil Eng* J. 4 (2010): 65-71.

61. Davoodi M, et al. (2007) Chemical and physical characterization of coarse bauxite residue (red sand) for concrete making. In: Proceedings of the conference Sustainable Construction Materials and Technologies, Coventry, England.

62. Gaur AS, et al. Effect of Partial Replacement of Cement by Ground-Granulated Blast-Furnace Slag and Fine Aggregate by Marble Slurry on Properties of Concrete. *Am J Eng Res*. 6.1 (2017): 28-31.

63. Segre N, et al. Use of tire rubber particles as addition to cement paste. *Cem Concr Res*. 30.9 (2000): 1421–1425.

64. Turatsinze A, et al. Mechanical characterisation of cement-based mortar incorporating rubber aggregates from recycled worn tyres. *Build Environ*. 40.2 (2005):221–226.

65. Topcu IB, et al. Properties of concrete containing waste glass. *Cem Concr Res*. 34.2 (2004): 267–274.

66. Humphrey D, et al. Replacement of Sand with Bauxite Mining Waste in Concrete Production. *J Mater Eng Struct*. 6 (2019): 525–534.

67. Fengling Z, et al. Effect of bauxite aggregate in cement composites on mechanical properties and resistance against high-velocity projectile impact. *Cem Concr Compos*. 118.8 (2021): 103915.

68. Original MA (2012) Red Sludge Production and Utilization Opportunities. Graduate Seminar, Süleyman Demirel University, Isparta, Turkey.

69. Raja RR, et al. Effective utilization of redmud bauxite waste as a replacement of cement in concrete for environmental conservation. *Eco Env Cons*. 19.1 (2013): 247-255.

70. Ahmed S, et al. Utilization of red mud for producing a high strength binder by composition optimization and nano strengthening. *Nanotechnol Rev*. 9 (2020): 396–409.

71. Wang L, et al. A Review on Comprehensive Utilization of Red Mud and Prospect Analysis. *Miner*. 9 (2019): 362.

72. Rajabi Ali M, et al. Evaluation of Mechanical Properties of Two-Stage Concrete and Conventional Concrete Using Nondestructive Tests. *J Mater Civ Eng* 32.7 (2020).

73. TS EN 197-1 (2002) "Cement: Part-1 General Cements-Composition Properties and General Rules", Turkish Standards Institute, Ankara, Turkey.

74. Tınmaz EK, et al. Cement based solidification / stabilization of red mud: Seepage properties of heavy metals Pamukkale University. *J Eng*. 23.6 (2017): 741-747.

75. Yıldız A, et al. Farklı kül ve çamur numunelerinin bertarafı amacı ile inşaat malzemesi olarak kullanılabilirliğinin incelenmesi. Türkiye, TÜBİTAK, 108Y233, 2009.

76. Yıldız A, et al. Recycling of red mud as a building material via a stabilization/solidification method. *Asian J Chem*. 25.1 (2013): 266-270.

77. TS 802, (2006) Concrete mixture design calculation principles, Turkish Standards Institute, Ankara, Turkey.

78. TS EN 12350-7. Testing Fresh Concrete – Part 7: Air Content – Pressure Methods. European Standards, 2009.

79. Özcan F, et al. Influence of ground pumice on compressive strength and air content of both non-air and air entrained concrete in fresh and hardened state. *Constr Build Mater.* 187 (2018): 382–393.

80. TS EN 12390-3 (2010) Testing hardened concrete – Part 3: Compressive strength of test specimens, Turkish Standards Institution, Ankara, Turkey.

81. Ince R, et al. Effect of aggregate granulometry on size change in split-tensile strength of cube specimens. *J Eng.* 28.3 (2017):443-451.

82. TS EN 12390-6 (Concrete-Hardened Concrete Tests-Part 6: Determination of Tensile Strength in Splitting of Test Specimens) 2010.

83. Karpuz O, et al. The Effect of fine aggregate type on wear resistance of pavement concrete, Electron. *J Constr Technol.* 5 (2009): 51–58.

84. ASTM C666-97, Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing. Annual Book of ASTM Standards, West Conshohocken, PA, 4.2 (1997).

85. ASTM C (2003) Standard test method for pulse velocity through concrete. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA19428-2959, United States.

86. Divakar Y, et al. Experimental Investigation on Behaviour of Concrete with the use of Granite Fines. *Int J Adv Eng Res Stud.* 1.4 (2012): 84-87.

87. Deshmukh MP, et al. Bulk utilization of industrial waste (bauxite residue) of red mud concrete. *J Mech Civil Eng.* 11.6 (2014): 01-03.

88. Raheem AA, et al. Effect of Curing Methods on Density and Compressive Strength of Concrete. I*nt J Appl Sci Technol.* 3.4 (2013): 55-64.

89. Danso H, et al. Performance characteristics of enhanced soil blocks: a quantitative review. *Build Res Inform*. 43.2 (2015): 253-262.

90. Aydin S, et al. Effect of aggregate Type on Mechanical Properties of Reactive Powder Concrete. *ACI Mater J.* 107.5 (2010): 441-449.

91. Binici H, et al. Investigating the sound insulation, thermal conductivity and radioactivity of chipboards produced with cotton waste, fly ash and barite. *Constr Build Mater.* 30 (2012): 826–832.

92. Sohaib MM, et al. Effect of fire and cooling mode on the properties of slag mortars. 31 (2001):1533–1538.

93. Awal A, et al. Effect of cooling regime on the residual performance of high-volume palm oil fuel ash concrete exposed to high temperatures. *Constr Build Mater.* 98 (2015): 875–883.

94. Li L, et al. Effects of cement dosage and cooling regimes on the compressive strength of concrete after post-fire-curing 800°C. *Constr Build Mater.* 142 (2017): 208–220.

95. Gupta T, et al. Effect of elevated temperature and cooling regimes on mechanical and durability properties of concrete containing waste rubber fiber. *Constr Build Mater.* 137 (2017): 35–45.

96. Benaicha M, et al. Correlation between the mechanical behavior and the ultrasonic velocity of fiber-reinforced concrete. *Constr Build Mater*. 101 (2015): 702–709.

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