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The Investigation of Use as Aggregate in Lightweight Concrete Production of Boron Wastes

Abudalrhman Aldakshe [a], Hakan Çağlar [a*], Arzu Çağlar [a], Çağrı Avan [a]

[a] *Faculty of Engineering and Architecture, Kastamonu University, Kastamonu, Turkey.*

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Abstract

Lightweight concrete manufacture has been aimed as a result of the use of boron waste which is aggregate of pumice, one of our natural resources, and a valuable industrial waste as a substitution material in different proportions (1%, 3%, 5%, 7%, and 9%). As a result of the study, it was aimed to obtain a water-resistant and lighter material which has higher properties than lightweight concrete in terms of physical and mechanical. The study was carried out as three stages. At the first stage, 90% of the pumice aggregate and 10% of the sand (Reference sample) were used and lightweight concrete was produced. At the second stage, boron waste at the rate of 1%, 3%, 5%, 7%, and 9% was used for pumice aggregate and the doped lightweight concrete sample was produced. At the last stage, tests were carried out for the determination of the physical and mechanical properties of lightweight concrete samples which were produced. For determination of mechanical properties, tensile splitting strength and compressive strength tests were performed. Additionally, specific gravity, water saturated unit volume weight, porosity, and capillary water absorption tests were made for the determination of physical diversities. It was found that the physical and mechanical properties of the material improved with the increase of boron waste in the consequence of this study. The best result was obtained with the boron waste substitution at the rate of 9%. Environmentally harmful boron wastes being used in the construction sector will contribute to sustainability by recycling the boron wastes.

Keywords: Lightweight Concrete; Pumice; Boron Waste; Physical Property; Mechanical Properties.

1. Introduction

The humankind needs various structures for sheltering and the most crucial element of these structures is the material. The life-span of a structure can be increased with the quality of the used material in its structure and suitable use of it [1]. The most used bearing construction element in construction sector is concrete [2]. Although it is commonly used, concrete which has high heat and sound conductivity and excess unit weight causes physical and mechanical problems in structures [3].

Improvements have occurred in the concrete industry thanks to the developments in technology [4]. The production of new concrete types was developed in order to improve negative sides of concrete actively used in the construction industry and produce more economical and functional concretes [5]. During this development process, different aggregate and additives have been used, mixture ratios have been changed. On the other hand, construction practice has been changed by using only normal aggregate and cement or it was resorted to producing special concretes by using a few of these methods together [6].

* Corresponding author: hakancaglar71@yahoo.com

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Special concretes have been manufactured in order to meet various expectations according to their place of use and intended purposes [7]. When special concretes are examined, lightweight concretes take the place at the top. Started to be commonly used, lightweight concretes has become a material providing technical and economic advantages for structures [8]. Lightweight concrete, having low unit weight, high insulating value, expected strength property, being non-combustible, also has importance in terms of architecture. The most typical characteristic of lightweight concrete that distinguishes it from conventional concrete is its lightness and it has cellular structure providing heat insulation. The pores within lightweight concrete are created by using porous aggregate or forming porous internal structure. In addition, lightweight concrete is obtained by forming gas bubbles within fine mortar material [9].

The most used method in lightweight concrete manufacture is the method that lightweight concrete manufactured by using porous aggregates. Generally, two types of aggregate are used in lightweight concrete manufacture: one is natural aggregates (pumice, diatomite, volcanic binders, etc.) and the other one is artificial aggregates (perlite, clay, sintered-fly ash, expanded shale, etc.) [10]. When studies are examined, it is seen that generally, lightweight manufacture is made by using pumice (natural aggregate). The reason is that pumice has high level of porous structure and is resistant to physical and chemical factors. Thanks to its porous structure, light and isolating pumice is the most preferred aggregate type in lightweight concrete manufacture [11].

In Kozak and Ünal (2010) study, lightweight concrete with the separate use of Isparta pumice and Afyonkarahisar tuff as aggregates has been produced. They determined the wear rate, amount of sludge material, unit volume weight, amount of organic matter, specific gravity, water absorption and grain distribution values in the aggregates used. They found heat conductivity, unit volume weight and pressure resistance values on the concrete. As a result, they stated that the low unit volume weights of lightweight aggregates used in the production of block elements cause the decreasing of the building self-weight of the block elements to be used in buildings [12]. Binici et al. (2010) [13] produced concrete by using barite, colemanite, pumice and blast furnace slag instead of fine aggregate and cement. They investigated the strength and durability of their reinforced concrete. They also examined the properties of wear resistance, sulphate resistance, permeability and freeze-thaw resistance for determination of physical properties. As a result of this study, they found that the samples with High Furnace Slag showed a severe resistance to sulphate effect and this resistance increased in proportion to the increased High Furnace Slag ratio. They also reported that the sulphate resistance of the pumice was good and that there was less mass loss compared to other materials. Hossain (2004) [14] investigated the physical properties of lightweight concrete produced by replacing it with basaltic pumice by 0-100% in volume instead of coarse aggregate. He experimented the lightweight concrete samples he produced on workability, superficial absorption, tensile splitting strength and compressive strength, permeability tests. As result of the study, he reported that the produced concrete had the appropriate density and compressive strength to be included in the lightweight concrete class and had low modulus of elasticity and high permeability when compared to the reference sample.

Sustainable environment and manufacturing durable materials are really important to protect the World. For this reason, wastes occurred should be utilized and their negative effects on environment should be eliminated. The wastes that occur during the disposal of raw materials, production or after consumption in the industrial sector pose danger in terms of environmental pollution [15-17]. Because of that physical and chemical recycling processes create additional investment costs, it is almost impossible to recycle all the wastes [18]. However, the use of waste materials in the areas of rapid development such as construction sector will reduce environmental pollution, and also eliminate additional investment costs [19]. There are various studies in the literature where many waste materials that cause environmental pollution are used as building material or filling material in the construction sector [20-22].

When studies on lightweight concrete has been examined, no study was discovered showing boron waste used in lightweight manufacture. For this purpose, an experimental study was carried out with regard to using pumice aggregate as an aggregate and boron waste as an additive in light concrete production in this study. In this context, as a result of using boron waste as additive, it was aimed to improve physical, mechanical and micro structure of lightweight concrete. Within this context, properties of material used within study has been presented and then experimental results have been shown. At the last part, the effects of results have been discussed with reference studies.

2. Materials and Methods

Processes were carried out according to Turkish Standards Institute at the materials used in studies and tests. Within this scope, cement was prepared according to TS En-197, aggregate according to TS EN 706, and mixture according to TS 2511. Tests were carried out according to TS EN 771 and TS EN 772.

2.1. Pumice

Pumice is a sponge-like, with high void rate, specific weight, and natural volcanic rock [23-25]. While defining pumice, known as glassy-aluminium silicate, chemical content is benefited. Its hardness is 5-6 Mohs and contains 75% silica (SiO2) [26]. Porosity ratio of pumice is 85% of its volume. In other words, pumice aggregate grain consists of 85% porosity and 15% solid matter [27]. Figure 1 shows internal structure of pumice aggregate.

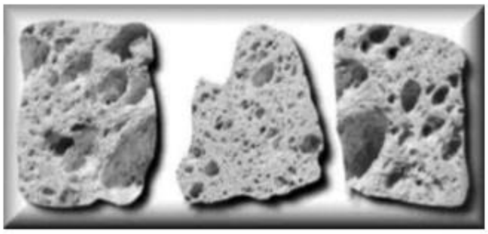

Figure 1. Porous structure of pumice aggregate

As the grain size of pumice increases, the percentage of pumice increases [28]. General physical and chemical properties of pumice rocks in Turkey are presented in Table 1 [29].

Table 1. General physical and chemical properties of pumice rocks in Turkey

Physical Properties	Analysis Value	Chemical Properties	Analysis Value
Colour	Light gray to dirty white	pH	7-7.3
Crystal Shape	Amorphous	Radioactivity	None
Crystal Juice	None	Amount of Water Soluble Substance (weight) %	< 0.15
Hardness (MOHS)	5.5-6.0	Amount of Water Soluble Substance (weight) %	≤ 2.9
Dry Unit Volume Weight (g/cm^3)	0.37-0.97	Volatile Substance (weight) %	None
Actual Specific Gravity	2.15-2.65	Interaction with acids	İnert
Porosity (%)	45-90	Exacerbations degree (^{0}C)	None
shrinkage (mm/m)	< 1	Melting Degree (^{0}C)	≤ 900
Thermal Conductivity Coefficient (W/mK)	0.08-0.2		
Heating Temperature (cal/g. ^{0}C)	0.24-0.28		
Sound insulation (dB)	40-55		
Water Absorption (weight) %	30-70		
Steam Diffusion Coefficient	5-10		

2.2. Boron and Boron Waste

Boron element is not found in nature without constraint [30]; although there are more than 250 boron mineral types on earth, very few of these minerals are of commercial importance [31]. Boron minerals are classified according to their calcium, sodium and magnesium elements within itself [32]. The economic value of minerals are determined by the B_2O_3 ratio within their structure. Boron minerals with commercial value are Tincal, Kernite, Colemanite, Pyodermite, Ulexite, Probertite, and Hydrobrasis [33-35].

Table 2. Boron minerals of commercial value

Structure	Mineral Name	Chemical Formula	%B_2O_3 rate	Location
Sodium Borate	Tincal	$Na_2B_4O_7.10H_2O$	36.5	Kırka, Emet, Bigadiç, USA.
	Kermit	$Na_2B_4O_7.4H_2O$	51.0	Kırka, USA, Argentina
Calcium Borate	Colemanite	$Ca_4B_6O_{11}.5H_2O$	50.8	Emet, Bigadiç, USA
	Pandermite	$Ca_4B_{10}O_{19}.7H_2O$	49.8	Sultançayır, Bigadiç
Sodium-Calcium Borate	Ulexite	$NaCaB_5O_9.\ 8H_2O$	43.0	Bigadiç, Kırka, Emet, Argentina
	Probertite	$NaCaB_5O_9.\ 5H_2O$	49.6	Kestelek, Emet, USA
Magnesium-Calcium Borate	Hydroboracite	$CaMgB_6O_{11}.\ 6H_2O$	50.5	Emet

A large part of the boron mineral deposits known in the world are located in the west of Turkey [36, 37]. The world's largest boron deposits with 72% share in regard to B_2O_3 content are controlled by the National Mining Company Eti Maden [38]. In Turkey, approximately 1,195,000 m^3 of boron waste is annually discharged to waste ponds in Kırka and Espey boron plants owned by Etibor Corp. holding boron operation plants [39, 40]. Boron waste recycling methods can be grouped under three titles. These are the acquisition of valuable content of wastes, utilization of the clay in proper sector and utilization of the wastes in proper sectors [41]. Boron mineral being in the form of raw coal with clay minerals enable the utilization of these wastes in the construction and ceramic industry. The use of waste clays containing boron minerals in the brick industry provides additional raw material to the sector, and also reduces the damage to the environment by the disposing the wastes in plants. Boron containing waste clays can be used in masse, frit and glaze construction in the glass industry, ceramic industry; and in construction sector, especially in cement industry, as concrete additive, padding material in road, bridge and dam construction [42, 43].

2.3. Cement

CEM I 42.5 N cement with specific gravity of 3.06 kg/m^3 was used in the production of light concrete. The values of the cement used were shown in Table 3.

Table 3. Values of cement

Physical Properties	Cement Values	Chemical Properties	Cement Value
2 day compressive strength (Nt/mm^2)	22.7	Loss of glow (%)	4.33
7 day compressive strength (Nt/mm^2)	35.0	Insoluble residue (%)	0.26
28 day compressive strength (Nt/mm^2)	45.3	Sulphur trioxide (SO_3) (%)	2.85
Socket start (min)	145	Chloride (Cl) (%)	0.0120
Volume expansion (mm)	1		

2.4. Mixing Water

In this study, city water used in Kastamonu Provincial Highways Regional Directorate was used as concrete mixing water.

2.5. Manufacture

In this study, 6 different series of light concrete samples (REF; reference sample, 1% BW, 1% boron waste doped sample, 3% BW, 3% boron doped sample, 5% BW, 5% boron waste doped sample, 7% BW, 7% boron waste doped sample, 9% BW; 9% boron waste doped sample) were produced. In light concrete production, the water / cement ratio was kept between 0.25-0.35. In the study, 90% pumice was used in the reference samples. In all lightweight aggregate samples, 1%, 3%, 5%, 7% and 9% of the boron waste (BW) additives were added to the sand mixture at the rate of 10% to increase strength. (Table 4).

Table 4. Aggregate ratios used in light concrete production

	Pumice (P) %	Boron waste (BA) %	Sand %
REF	90	0	10
%1 BA	89.1	1	10
%3 BA	87.3	3	10
%5 BA	85.5	5	10
%7 BA	83.7	7	10
%9 BA	81.9	9	10

Firstly, lightweight aggregates were put in the mixer and blended by adding the amount of water determined for the pre-saturation process and thus the mixture was ensured to absorb the water. And then the mixture was blended until it became homogeneous by adding natural. Mixing process was continued by adding cement to the composed mixture. Finally, a homogeneous mixture was obtained by adding the water determined in the mixture calculation to the mixture and the mixing process was ended. Prepared lightweight concrete mixture was placed in 15×15×15 cm^3 cubic mould. The lightweight concrete samples whose hardening were completed removed from the mould 1 day later and cured in the curing pool at + 20°C for 28 days. After curing process, lightweight concrete samples were tested to determine the physical and mechanical features of them.

3. Results and Discussion

3.1. Results of Physical Tests Applied to Samples

Physical test results of reference samples and boron waste doped lightweight concrete samples were presented in headings. Table 5 presents specific gravity, water saturated unit volume weight, capillary water absorption quantity and porosity test results for the determination of the physical properties of the reference sample. For each experiment, 144 lightweight concrete samples were used.

The given table contains the values obtained by taking the arithmetic average of the samples. When table is examined, it is seen that the specific gravity of the reference sample is 1.60 g/cm^3, water saturated unit volume weight is 1.24 g/cm^3, the capillary water absorption rate is 120 g and the porosity is 22.0%. It is seen that the specific gravity of the boron waste doped lightweight concrete sample with 1% is 1.57 g/cm^3, the water saturated unit volume weight is 1.27 g/cm^3, the capillary water absorption amount is 114 g and the porosity is 21.4%. It is determined that the specific gravity of boron waste doped light concrete sample with 3% is 1.50 g/cm^3, water saturated unit volume weight is 1.34 g/cm^3, capillary water absorption amount is 108 gr and porosity is 21,0%. It is seen that the specific weight of the boron waste doped lightweight concrete sample with 5% is 1.46 g/cm^3, the water-saturated unit volume weight is 1.39 g/cm^3, the capillary water absorption amount is 100 gr and the porosity is 20.4%. It is seen that the specific gravity of the boron waste doped lightweight concrete sample with 7% is 1.41 g/cm^3, the water saturated unit volume weight is 1.43 g/cm^3, the capillary water absorption amount is 96 gr and the porosity is 19.6%. It is determined that the specific gravity of boron waste doped light concrete sample with 9% is 1.37 g/cm^3, water saturated unit volume weight is 1.49 /cm^3, capillary water absorption amount is 90 gr and porosity is 19.1%.

Table 5. Physical test results

Physical Tests	Ref.	%1 BA	%3 BA	%5 BA	%7 BA	%9 BA
Specific Weight (g/cm^3)	1.60	1.57	1.50	1.46	1.41	1.37
Water Saturated Unit Volume Weight (g/cm^3)	1.24	1.27	1.34	1.39	1.43	1.49
Capillary Water Absorption (g)	120	114	108	100	96	90
Porosity (%)	22.0	21.4	21.0	20.4	19.6	19.1

3.2. Results of Mechanical Tests Applied To Samples

Figure 1 shows the compressive strength and tensile splitting test results for the determination of mechanical properties of samples. #6 lightweight concrete samples were used for each experiment. The given table contains the values obtained by taking the arithmetic average of the samples.

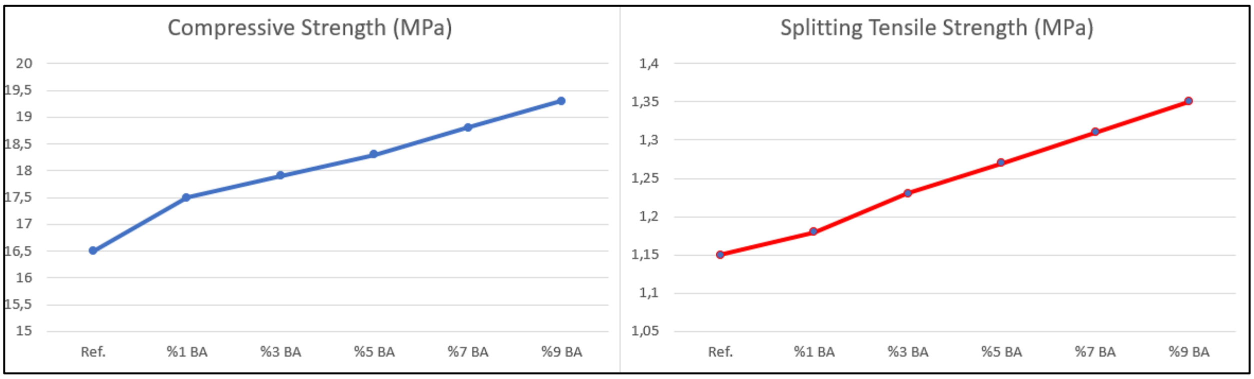

Figure 1. Mechanical test results

In Figure 1, it can be seen that compressive strength belonging to reference sample is 16.5 MPa, tensile splitting strength is 1.15 MPa. Furthermore, when the table is examined; it is seen that the compressive strength of the boron waste doped lightweight concrete sample with 1% is 17.5 MPa and the tensile splitting strength is 1.18 MPa. It is determined that the compressive strength of the lightweight concrete sample with 5% boron waste doped is 18.3 MPa, the tensile splitting strength is 1.27 MPa while the compressive strength of the lightweight concrete sample with 3% boron waste doped is 17.9 MPa and the tensile splitting strength is 1.23 MPa. It is seen that the compressive strength of the boron waste doped lightweight concrete samples with 7% is 18.8 MPa and the tensile splitting strength is 1.31 MPa. It is seen that the compressive strength of boron waste doped lightweight concrete sample with 9% is 19.3 MPa and tensile splitting strength is 1.35 MPa (Table 6).

Table 6. Mechanical test results

Mechanical Tests	Ref.	%1 BA	%3 BA	%5 BA	%7 BA	%9 BA
Compressive Strength (MPa)	16.5	17.5	17.9	18.3	18.8	19.3
Splitting Tensile Strength (MPa)	1.15	1.18	1.23	1.27	1.31	1.35

3.2. Discussion

Physical properties and mechanical properties of lightweight concrete samples manufactured within the scope of the study have been dealt with comparatively. The following is a discussion of the results of this study.

While the reference sample has the highest specific gravity with 1.60 g/cm^3, it has been seen that the 9% boron waste dope has the lowest value with 1.37 g/cm^3. In addition, it was found that when the amount of boron waste increases, the specific gravity of the sample decreases. When examined in terms of water saturation, it was determined that reference sample has low water saturated weight per unit of volume with 1.24 g/cm^3 while boron waste doped samples with 9% has highest value with 1.49 g/cm^3. İt was determined that water saturated unit volume weight of samples will increase in parallel with the increase of boron additive capillary absorption amounts of the materials are related to visible and invisible pores within themselves [44]. The more pores the material has, the more capillary water absorption amount there is; the lower the pore ratio it has, the lower the capillary water absorption amount. When capillary water absorption amount of lightweight concrete samples has been examined, it is seen that the reference amount has the highest capillary water absorption amount, and boron doped sample with 9% has the lowest water absorption amount. The study shows that when boron waste amount increase, capillary water absorption amount decrease. This is why boron waste fills the pores within lightweight concrete sample.

When porosity values of lightweight concrete sample are examined, reference sample has the highest porosity value, while boron waste doped lightweight concrete sample with 9% has the lowest porosity value. It has been determined that when additive amount added to samples have increased, porosity values have decreased. It can be said that this results from boron waste filling the pores within the sample structure as mentioned in comparison of capillary water absorption amounts. When it is evaluated with capillary water absorption amounts, lightweight aggregate concrete has high porosity and high capillary water absorption amounts. While boron waste additive has decreased the porosity, it has decreased the capillary water absorption amount. This decrease means that lightweight concrete sample takes less water to its structure. This will both extend the life of concrete in the long term and will not affect the comfort conditions negatively. When the compressive strengths of lightweight concrete samples are examined, it has been seen that the compressive strength of the reference sample has the lowest compressive strength value of 16.5 MPa and samples boron waste doped with 9% has the highest value of 19.3 MPa. Also, it has been determined that when boron waste amount has increased, compressive strength also has increased. The data obtained as a result of compression test has a strength value over strength value specified for lightweight concrete in ACI 213R-87 by using pumice aggregate (17.2 MPa). This situation has shown that lightweight concrete can be produced by using the ratios specified in this study. Compressive strengths of 21.0–29.4 MPa which Kabay and Aköz (2012) [44] have obtained in their studies are higher than the values found here because of their usage of crushed sand as a fine aggregate. Concrete strength (10-12-15-16-19-21 MPa) produced only by using coarse and fine pumice by Hossain et al. (2011) [45] had higher values. The reason is that the sand and boron waste are added by 10% while lightweight concrete samples are being produced.

When tensile splitting strength of lightweight concrete has been examined, it has been seen that while reference sample has the lowest tensile splitting strength value, boron waste doped lightweight concrete samples with 9% have the highest value. It has been determined that when boron waste amount increases, tensile splitting strength also increase. Consequently, the use of material with low specific gravity such as pumice as aggregate will allow to decrease specific gravity of the structure. Thus, it will enable the structure to be exposed to earthquake load at lower level. Also, boron wastes have significant effects on strength. The use of boron wastes in lightweight concrete manufacture will both protect environment by disposing wastes and reduce the waste storage cost. The utilization of boron wastes which is an industrial waste will ensure to recycle B2O3 within waste.

4. Conclusions

In this study, various percentages of boron waste were used as aggregate in the range of 1%, 3%, 5%, 7%, and 9%. The physical and mechanical properties of lightweight concrete samples were investigated. The main conclusions of the current study can be summarized as follows:

- The results recorded an increasing in the compressive strength (19.3 MPa) of samples with boron waste of 9% as compared with reference sample (16.5 MPa);
- The results displayed that using the pumice as aggregate will decrease the specific gravity of the structure;
- It has been seen that using the boron wastes as an industrial waste will secure to recycle B2O3 within the waste. The utilization of boron wastes which is an industrial waste will ensure to recycle B2O3 within waste;
- Further experimental studies utilizing additional data should be achieved to inspect the behavior of the concrete production utilizing the Boron waste as aggregate, as well as to analyze a more extensive range of parameters.

5. Conflicts of Interest

The authors declare no conflict of interest.

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