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INVESTIGATION OF STRUCTURAL LIGHTWEIGHT CONCRETE PRODUCTIBILITY WITH USING ERZINCAN RAW PERLITE AGGREGATE

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Abstract: A study was carried out on the production of structural lightweight concrete using raw perlite aggregate with a maximum aggregate particle diameter of 12.5 mm and granulometry conforming to the Fuller equation. For this, Concrete samples with five different cement dosages such as 150, 200, 250, 300 and 350 kg/m^3 and two different slump values were prepared, to regulate the workability of fresh concrete, 1% of cement weight plasticizer was added to all mixes. The physical and mechanical properties of fresh and hardened concrete were determined according to the relevant standards of ASTM. According to the research results, it has been seen that it is possible to produce structural lightweight concrete with a unit weight of between 1600 and 1900 kg/m^3 using perlite aggregate. The highest compressive strength of 35 MPa was reached after 90 days with a binder amount of 350 kg/m^3. According to the results of the research, one of the most effective parameters on the mechanical and physical properties of concrete is the slump value and the other is the amount of binder. The split tensile strength of the produced concrete was 11% of the compressive strength and the water absorption rate was 8%.

Keywords: Compressive strength, Raw perlite aggregate, Structural lightweight concrete, Unit weight, Tensile strength; Water absorption

Erzincan Ham Perlit Agregası Kullanılarak Taşıyıcı Hafif Beton Üretilebilirliğinin Araştırılması

Öz: Maksimum agrega tane çapı 12.5 mm olan ve granülometrisi Fuller denklemine uygun olan ham perlit agregası kullanılarak taşıyıcı hafif beton üretimi üzerine bir çalışma gerçekleştirilmiştir. Bu amaçla; 150, 200, 250, 300 ve 350 kg/m^3 olmak üzere beş farklı çimento dozajında ve iki farklı çökme (slump) değerinde beton numuneleri hazırlanmıştır. Taze betonun işlenebilirliğini düzenlemek amacıyla, tüm karışımlara çimento ağırlığının %1'i oranında akışkanlaştırıcı katkı ilave edilmiştir. Taze ve sertleşmiş betonun fiziksel ve mekanik özellikleri ASTM standartlarına göre belirlenmiştir. Araştırma sonuçlarına göre; perlit agregası kullanılarak 1600 ile 1900 kg/m^3 birim hacim ağırlığı arasında taşıyıcı hafif beton üretiminin mümkün olduğu görülmüştür. En yüksek basınç dayanımı, 350 kg/m^3 bağlayıcı miktarıyla 90 gün sonunda 35 MPa olarak elde edilmiştir. Araştırma sonuçlarına göre; betonun mekanik ve fiziksel özellikleri üzerinde en etkili iki parametre çökme değeri ile bağlayıcı miktarıdır. Üretilen betonların yarmada çekme dayanımı, basınç dayanımının %11'i olarak belirlenmiş ve su emme oranı %8 olarak tespit edilmiştir.

Anahtar Kelimeler: Basınç dayanımı, Ham perlit agregası, Taşıyıcı hafif beton, Birim hacim ağırlığı, Çekme dayanımı, Su emme oranı

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1. INTRODUCTION

The use of lightweight concrete dates back to 3000 BC (Aitcin, 1998; Thienel et al. 2020; Surahyo et al.2019). In Europe, 2000 years ago, the Romans built their temples and statues using lightweight concrete. The interesting thing is; It is the use of pumice, perlite, scoria and similar lightweight aggregates, which are volcanic rocks, as aggregates in various parts of the world today (Aitcin, 1998; Kirca, 2018; Surahyo et al.2019). In the first years, natural lightweight aggregates such as pumice, scoria, tuff, perlite and similar volcanic origin rocks were used. These lightweight aggregates are used instead of both coarse and fine aggregates. The majority of lightweight aggregates used as fines have pozzolanic activity (Aitcin, 1998; Chandara and Berntsson, 2003). Erdoğan (2003); states that the historical artifacts in Ephesus and Milas can survive until today without deterioration, if the rocks and binders used in the structures here have pozzolanic activity. Light aggregates with pozzolanic activity, especially by reacting with free lime (CaOH) released as a result of the hydration of the cement forming calcium silicate hydrate (C-S-H) which has a binding feature so that increasing the strength and density of the cement matrix and arranging the void structure and improving the mechanical and physical properties of the concretes produced. It makes a significant positive contribution to their durability (Chandara and Berntsson, 2003; Eroğan, 2003; Short and Kinniburgh, 1978; Hossain 2004; Neville 1996; Surahyo et al.2019). The advantages of lightweight aggregates have made the use of these aggregates widespread throughout the world (Chandara and Berntsson, 2003; Surahyo et al.2019).

The fact that these aggregates are not available everywhere so that it has led some countries to produce lightweight aggregates in factories. Natural materials such as clay, fly ash, shale, slate and blast furnace slag were generally used for the production of lightweight aggregates in the factories. Many researchers such as Neville (1996), Aitcin (1998), Chandra and Berntsson (2003), Kirca, 2018 and Kayali et al. (2003) stated that it is possible to produce lightweight concrete with these aggregates. The advantages of lightweight concrete have popularized the use of these concretes and made their use mandatory. The fact that these concretes are light, their heat transmission is lower than normal concretes, and that their pozzolanic activity and durability increase over time have made the use of these concretes in some buildings mandatory (Chandara and Berntsson, 2003; Neville, 1996). The increase in demand for this concrete has led to an increase in research and studies to increase the strength and some properties of these concretes. Researchers such as Neville (1996), Aitcin (1998), Kayali et al. (2003). Surahyo et al.2019 states that lightweight aggregates have very low strength compared to normal aggregates and they also said that it is possible to eliminate this low strength in lightweight aggregates with the use of high strength binders. In the early days, lightweight concretes were used for heat insulation purposes. The unit weights of these lightweight concretes were changed between 300 and 800 kg/m3. In later studies, it has been seen that some lightweight concrete can be used as structural concrete. However, the unit weights and heat transmission of these lightweight concretes are considerably higher than the lightweight concretes used for heat insulation (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Neville,1996). It is seen that these values are 25-30% lower when compared to the values of normal weight concretes. One of the important properties of lightweight aggregates is; It contributes to the increase in strength and durability of concrete by reacting with the free lime contained in the cement. The aim of this study is to investigate the usability of raw perlite aggregate as an alternative aggregate in structural concrete to be produced in Erzincan an earthquake zone.

2. STUDY AREA

The design of lightweight concrete differs considerably from the design of normal concretes (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004; Neville ,1996; Kirca, 2018; Kayali et al. 2003; Surahyo et al.2019). Most of the time in the designs of lightweight concretes a full relationship between strength and workability, which is one of the functional requirements, is not observed. However, in the design of normal concrete, there is a very close relationship between these two properties, and the designs are made to provide these two properties. Therefore, it is recommended to use different methods in different lightweight concrete designs. A lot of work has been done on the factors that will affect the properties of normal concrete and necessary information has been obtained. Adequate studies have not yet been carried out on the factors that will affect the properties of lightweight concrete and sufficient information has not been obtained (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004; Neville,1996; Surahyo et al.2019; Kirca, 2018). Recently, with the increase in the need for lightweight concrete use worldwide, studies on this subject have intensified. One of the disadvantages here is that different lightweight aggregates have very different properties and a different design method is needed for each aggregate. Researchers have created an archive by determining the physical and mechanical properties of the concrete they obtained by using some different lightweight aggregates. However, this information has not reached sufficient level yet. One of the most effective factors on the physical and mechanical properties of the concrete to be produced is the aggregate particle size and granulometry. Some standards, such as ASTM and BS, recommend some granulometers for the production of structural lightweight concrete. These standards and researchers suggest that the maximum aggregate particle size to be used in the production of structural lightweight concrete should be between 10 and 14 mm. One of the basic principles in the design of lightweight concrete is that the concrete to be produced has the desired workability. The surface texture and shape of the light aggregate and the coarse aggregate surface texture of the fine aggregate have a reducing effect on the workability of the concrete produced using these aggregates (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004; Neville,1996). One of the most basic problems in the design of lightweight concrete is that it is very difficult to produce concrete with the desired workability. To avoid this problem, the fine aggregate volume should be at least 50% of the total aggregate volume (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004; Neville,1996; Kayali et al., 2003).

The workable characteristics of lightweight aggregate concrete are quite different from those of concrete produced with normal aggregate. While a wide range of workability is achieved in a wide range of water content in concrete produced using natural aggregates, workability can be very low when the same amount of water is used in lightweight aggregates. If the workability of lightweight concrete is too low, it will not be possible to compact the concrete or to place it by bottling. When a vibrator is used, the light coarse aggregates float to the surface and cause segregation in the concrete (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004) The most appropriate test method to measure the workability of lightweight concrete is the compaction factor test method. A lightweight aggregate concrete with a compaction factor value of 0.8 to 0.9 has quite good workability (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004; Kayali et al., 2003). Another test used to measure the workability of these concretes is the VB test. The VB value of a workable lightweight aggregate concrete should be less than 15 seconds (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Neville,1996). In terms of the difficulty of applying these two methods in practice, the use of the slump test is recommended. It is sufficient that the slump values of workable lightweight concretes are between 60-130 mm (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004; Neville,1996; Kayali et al., 2003).

3. MATERIAL AND METHOD

3.1. Material

Considering the sensitivity of the study, importance was given to ensure that the cement to be used in the study complies with the standards. In the research, CEM I 42.5 N, produced in Set Çimento Ankara Factory in accordance with TS EN 197-1, was used as cement Physical, chemical, mechanical properties and related standard limit values of these cements are given in Table 1. Together with water, cement and aggregate, it is one of the basic materials that make up concrete (Aitcin, 1998; Erdoğan, 2003; Neville,1996). The water to be used in the production and maintenance of concrete should be clean and should not contain foreign materials such as clay, silt, organic matter, acid, chloride, sulfate, oil and industrial wastes that may have a detrimental effect on the properties of fresh and hardened concrete (Neville, 1996; Faust and König, 1998; Kirca, 2018). The properties of water affect the quality of the concrete to be produced at least as much as cement and aggregate (Faust and König, 1998; Neville,1996; Erdoğan, 2003). Therefore, in this study, water supplied from Erzincan city drinking water network was used as mixing and maintenance water. Aggregate to be used in the production of structural lightweight concrete should be chosen very carefully (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004; Neville, 1996; Kayali et al.2003). Since it contains very large voids in lightweight aggregates, it is both low-strength and brittle and reduces the workability of concrete by absorbing excessively water (Chandara and Berntsson, 2003; Hossain, 2004; Neville, 1996; Kayali et al.2003; Zhang and Gjorv, 1991). In this study, raw perlite aggregate obtained from Erzincan molla-village and granulometry in Table 2 was used.

Table 1. Chemical composition, physical and mechanical properties of CEM I 42.5 N

Components (%)		CEM I 42.5 N	TS EN 197-1
CaO		64.02	---
SiO_2		20.31	---
Al_2O_3		5.64	---
Fe_2O_3		3.27	---
MgO		1.64	≤ 5.00
SO_3		2.86	≤ 4.00
K_2O		0.8	---
Na_2O		0.87	---
Loss of ignition (%)		0.9	≤ 5.00
insoluble residue		0.31	≤ 5.00
main components			
C3S		55.55	---
C2S		16.5	---
C3A		9.41	---
C4AF		9.95	---
Serb. CaO		1.48	---
Physical and Mechanical Properties			
Specific density (g/cm^3)		3.11	---
Blaine (cm^2/g)		3489	---
200 µm sieve (%)		---	---
90 µm sieve (%)		0.3	---
40 µm sieve (%)		8.4	---
volume expansion (mm)		2	≤ 10
Set time	beginning (min)	145	≥ 60
(minutes)	end	230	---
Compressive strength (MPa)	7 day	38.8	---
	28 day	45.78	≥ 42.5

3.2. Method

Design of lightweight aggregate concrete differs from those of normal and high-strength concrete produced with normal weight aggregates and are quite difficult. Because water absorption, specific gravity, moisture and the amount of fine material in the mixture of the aggregates used in the production of lightweight concrete are highly variable (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004; Neville, 1996; Kayali et al.2003; Nadesan and Dinakar, 2017; Thienel et al.2020). The most important challenge in the design of lightweight concrete is that different lightweight aggregates have very different properties and absorb water very quickly (Chandara and Berntsson, 2003; Neville, 1996; Zhang and Gjorv, 1991; Hoff, 1990; Nadesan and Dinakar, 2017; Thienel et al.2020). Very rapid water absorption of these aggregates causes the concrete produced with these aggregates to lose their consistency in a short time and to lose their workability before the concretes are placed (Hoff, 1990; Novokshchenov and Whitcomb, 1990; Malhotra, 1990; TSE 2511, 2017).

Many researchers: They suggested that lightweight aggregates should be pre-wetted just before mixing, thus preventing the aggregates from absorbing the mixing water of the concrete during mixing, transportation and placement. As can be seen here, there are many variables in the design of lightweight concrete, and these variables vary according to the lightweight aggregate used. So that makes the design of these concretes very complex and difficult. Total required amount of aggregate is taken according to loosen dry-unit weight. This amount is generally appropriate to be taken as 1 to 1.2 m^3 for 1 m^3 of concrete (ASTM C330/C330M-17a, 2022). One of the most important factors that will affect the properties of the concrete to be obtained is the granulometry of coarse and fine aggregates and their proportions. Well graded aggregates have a uniform particle distribution and a minimum void ratio and require minimum cement paste (Aitcin,1998; Erdoğan, 2003; Neville,1996; coarse and fine). This provides very economical cement usage. The amount of fine aggregate required for an ideal mixture and workability should be between 40% and 65% of the total aggregate volume (Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Hossain, 2004; Neville, 1996; ASTM C330/C330M-17a, 2022; ASTM E 11, 1995). Short and Kinniburg (1978), Neville (1996), Aitcin (1998), Hossain (2004) and many researchers state that the fine aggregate ratio should be 50% or more for the production of workable lightweight concrete. In this study, aggregate maximum grain size of 12.5 mm was chosen. In the selection of granometer, Fuller's equation, ASTM E 11, ASTM C330 and previous studies were considered. Aggregate granulometry was chosen according to information which was suggested by the standards and studies. It was given in the table 2.

Table 2. Aggregate mix percentages

Aggregate grain size (mm)				
12.5-9.5 mm	9.5-4.75 mm	4.75-2.36 mm	2.36-0.30 mm	300-0 µm
Mixing ratios (%)				
10	25	30	25	10

In this study, 1.2 m^3 of aggrege was taken for the production of one m^3 of concrete, the amount of cement at different doses between 150-350 was taken as the binder, to contribute to the workability, the mixtures were prepared by adding 1% of the cement weight plasticizer to the mixtures and adding water to create 70- or 120-mm slump. Necessary corrections were made according to the results obtained.

If there is no data available for the selection of the amount of cement to be used, the mechanical and physical properties of the concrete should be determined by adding cement in various proportions, or by using the amount of cement given for some lightweight aggregates and then necessary corrections should be made (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; Kayali et al.2003; Nadesan and Dinakar, 2017; Thienel et al.2020). Since there has not been any study on perlite aggregate to the production suitability of structural concrete, so that in this study 150, 200, 250, 300 and 350 dosed mixtures were made in order to determine the appropriate cement amount, and it was tried to determine the changes in compressive strength and some properties depending on the amount of cement.

The minimum amount of water to be added to the structural lightweight concrete mixtures should be in an amount that will enable easy mixing, transportation, placement, compaction and finishing of the fresh concrete (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; Neville, 1996; Kayali et al.2003; Annual Book of ASTM standards, 1995; Kirca, 2018; Thienel et al.2020). Excess water used in the mixture causes segregation, decrease in compressive strength and durability, increase in shrinkage (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; ASTM C39/39M,2022). Since the aggregates used in the production of lightweight concrete absorbs water very quickly and for a long time so that it is very difficult to determine a constant amount of water in the mixtures of such concretes (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; Kayali et al.2003). In previous studies, suitable slump value was suggested instead of constant water amount in the design of lightweight concrete. In this study, due to the difficulty of determining the fixed amount of water, mixtures were made based on the slump values of 70 and 120 mm instead of the fixed amount of water.

3.3. Mixing concrete

Putting all the materials used in the mixture into the concrete mixer at the same time causes the cement to clump together due to the rapid absorption of water by the lightweight aggregates. This reduces the binding property of the cement paste and its homogeneous distribution in the mixture (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; Neville, 1996; Kayali et al.2003; Kirca 2018; Nadesan and Dinakar, 2017; Thienel et al.2020). There is no rule in the standards as to which of the materials whose mixing ratios are determined should be put into the mixer first, and which should be added gradually. On the other hand, according to the experiences obtained from the applications, the order of placing the materials in the mixer and the applied method affect the homogeneity of the concrete to some extent (Chandara and Berntsson, 2003; Erdoğan, 2003; Short and Kinniburg,1978; Neville, 1996; Kayali et al.2003; Öztaş, 1993; Kirca 2018; Nadesan and Dinakar, 2017; Thienel et al.2020). In this study, a conventional rotary drum concrete mixer with a capacity of 150 dm3 was used to mix the concrete. First, coarse and fine aggregates were put into the mixer and water was added as much as the aggregate water absorption rate and the mixer was mixed for five minutes. After waiting for an hour, the mixer started for two more minutes. Cement was then added gradually while the mixer was running, and the mixer was running for another 2 minutes. Then, two-thirds of the mixing water was added to the mixture within two minutes while the mixer was running. The remaining water was added to the mixer by mixing with the plasticizer, and the mixing process continued for three more minutes, and the mixing process was completed.

3.4. Molding and curing of concrete

Cylindrical and cube molds with dimensions of 100/200 and 100x100x100,150x150x150 mm were used in the molding of concrete. The sample was filled into the molds in three equal layers, and each layer was compacted 25 times with a steel bar. After the filling and compacting process was completed, the mold surfaces were hit with a plastic hammer so that there would be no gaps in the concrete. After the concrete surface was finished with a trowel, it was kept in the laboratory for 24 hours and the upper surface of the sample was covered with a damp cloth to prevent water loss that may occur in the samples during this time. At the end of 24 hours, the samples were removed from the mold without being disturbed and placed in curing tanks saturated with lime at 23±1 C^0 and cured there until the time of the experiment.

4. RESULT AND DISCUSSION

4.1. Determination of mechanical properties of concrete

Standard compressive strength of concrete; It is the strength of 28-day samples cured in water at 23±1C^0 under axial compressive force (Aitcin, 1998; Erdoğan,2003; Neville, 1996). To determine the compressive strength of the produced concrete; Compression strength tests were performed on three 150x150x150 mm cube samples after 7, 21, 28, 60, and 90 days, according to ASTM C 39 and TS EN 1352 standards, using an ELE 2000 Auto digital display and speed-controlled compression test press. The arithmetic mean of the results from these three samples was taken as the compressive strength value of the respective sample. Additionally, to determine the effect of size, compression strength tests were performed on three 100/200 cylinders and three 100x100x100 mm cube samples after 90 days, according to ASTM C 39 and TS EN 1352, and the average of the results of these tests was taken as the compressive strength value. Since concretes have very high pressure and very low tensile strength, they cannot be used alone as carriers in structures. They can only be used as composite materials such as reinforced concrete in structures (Aitcin, 1998; Erdoğan,2003; Neville, 1996; Ersoy, 2013; ASTM C29/C29, 2022). From this point of view, the tensile strength of concrete is not of great importance, but the tensile strength of concrete is at least as important as the compressive strength, because the capillary tensile cracks in the sections cause large decreases in the bearing capacities of the sections and corrosion in the reinforcements. For this reason, it is of great importance to determine the tensile strength of concrete. The tensile strength of normal concrete is approximately 10% of the compressive strength (Aitcin, 1998; Neville, 1996; Badarloo et al.2018; ASTM C29/C29, 2022). The tensile strength of lightweight concrete with the same compressive strength is between 1/2 and 2/3 of the tensile stress of traditional concretes (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; Badarloo et al.2018; Annual Book of ASTM Standars, 1995). The reason of this; Lightweight aggregates break at lower shear forces due to the number and size of the voids in them. Apart from the bending test, the tensile stresses of concrete can be determined by direct or most direct methods. to determination of tensile strength of concrete, Indirect methods are generally used because of the difficulty of applying the direct tensile stress method. In these tests, the compressive force that will create the tensile stress that will cause the concrete to break is applied on the concrete. The most used indirect test is split tensile strength. In this test, a linear load is applied along the specimen axis and the load P, which causes the concrete to break, is found. This test can be applied to both cylindrical and cube samples (Annual Book of ASTM standards, 1995). In this study, In the experiment, 150x150x150 mm steel bars were placed opposite each other at the middle of the 150x150x150 mm cube samples, at the bottom and top, and the loading speed of the press was adjusted to be 2 KN/s, and the P loads that caused the samples to break were read from the screen of the press. The tensile stress of concrete is found in f_{cts} equation 1 by substituting the fracture load P and the steel bar size S.

$$f_{cts} = 0.642 * \frac{P}{(2*S)} \tag{1}$$

The experiment was repeated on three samples, and the average of these three experiments was taken as a result.

4.2. Determination of workability of fresh concrete

As with normal concrete, one of the most important properties of lightweight concrete is their workability when fresh. The workability characteristics of lightweight concrete differ considerably from those of normal weight concretes (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; Chen and Liu, 2005; Kim et al.2012). If the consistency of these concretes is too low, there will be a placement problem and as a result of the use of vibrators, light fine materials and coarse aggregates will float to the surface (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; Kayali et al.2003). This causes a decrease in the strength and durability of concrete. If the consistency is too high, it will decrease the cohesion of the concrete and increase the risk of segregation during transportation, pouring and placing, and at the same time, the solid part moves towards the bottom and so that the water moves towards the surface and it causes to reducing of the cross-section (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; Kayali et al.2003). In most of the studies, they recommend the compaction factor test or the vebe test instead of the slump test in determining the workability of lightweight concretes. For a workable lightweight concrete, it is sufficient for the compaction factor test value to be between 0.8 and 0.9 and the VEBE value to be less than 15 seconds (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Neville, 1998; Kayali et al.2003; Öztaş, 1993). Neville (1996), Short and Kinniburg (1978), Hossain (2004) and many other researchers, taking into account the difficulties of these tests in practice, so that they accept slump test is appropriate in determining the workability of structural lightweight concrete and that for a workable lightweight concrete, the slump test value is between 60 to 130 mm.

4.3. Determination of unit weight of fresh concrete

The unit volume weight of fresh concrete was determined according to ASTM C 138. Before the experiment, the weight and volume of the unit weight bucket were determined precisely. Then the unit weight bucket was filled in two equal layers, and each layer was compacted separately with a vibrator. After the surface was finished, the weight was recorded by weighing. This event was repeated three times for each concrete sample. Calculation was made according to ASTM C 138 and the arithmetic average of these three experiments was taken as the fresh unit volume weight of that sample. Unit weight and water absorption rates of hardened concrete were determined according to ASTM C 567. First, the samples were dried to a constant weight of $105 \pm 5C^0$ in the oven and cooled to $20\text{-}25C^0$ in the desiccator. After the samples were weighed on a scale with a precision of 0.001, they were kept in water for 48 hours to fill the gaps with water. The samples that became saturated with water were weighed by wiping their surfaces and their saturated dry surface weights were determined. Then, the saturated dry surface samples were weighed in water and their weights in water were determined. Using the data obtained, the unit weights and water absorption rates of the concrete were calculated according to ASTM C567.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The results of mineral analysis tests on aggregate are given in Table 3 and Figure 1. According to these results, it can be said that the aggregate is a volcanic rock with high amounts of SiO_2, Al_2O_3 and trace amounts of Fe_2O_3, FeO, MnO, MgO, CaO and K_2O.

Table 3. Chemical composition of perlite aggregate

Element	Weight	Atomic%	Net Int.	Error %	Kratio	Z	R	A	F
OK	48.09	61.75	311.40	8.03	0.22	1.06	0.98	0.43	1.00
NaK	5.04	4.50	45.52	10.44	0.03	0.96	1.00	0.54	1.01
ALK	9.31	7.08	141.75	5.83	0.07	0.93	1.01	0.78	1.02
SiK	33.81	24.72	503.88	4.18	0.26	0.95	1.02	0.81	1.00
KK	3.75	1.97	32.28	8.65	0.03	0.88	1.05	0.93	1.01

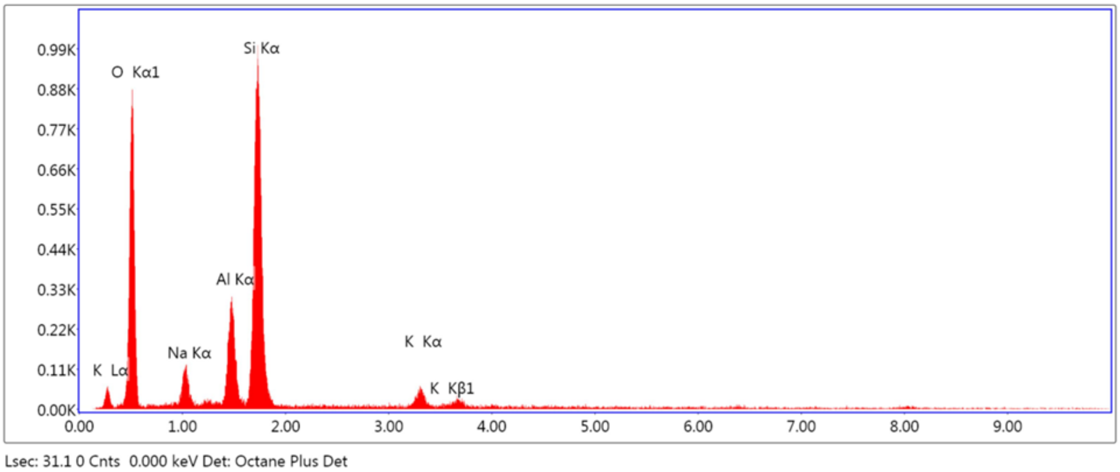

Figure 1: Mineral analysis of perlite aggregate

It was observed that the loose and compacted unit weights of the raw perlite aggregate changed depending on the grain age and increased inversely with the grain diameter. This is due to the large amount of spaces in the coarse aggregates or between the grains. According to ASTM C29/C29M-07, Gamphir (1986), Holm and Ries (1994), Neville (1996), Erdoğan (2003); define lightweight aggregate as aggregate with a loose unit weight of less than 1200 kg/m^3 for fine aggregates and less than 950 kg/m^3 for coarse aggregates. As seen in Table 4, the loose unit weight of the raw perlite aggregate is lower than the limit values specified for lightweight aggregates. The specific weight of lightweight aggregates should be less than 2.4 g/cm^3 (Chandara and Berntsson, 2003; Short and Kinniburg,1978; Hossain, 2004; Öztaş, 1993; Hoff, 1990; Kirca, 2018; Numan et al.2019; Thienel et al.2020). As seen in Table 4, the values found in this study are lower than 2.4 gr/cm^3 stated in the literature. At the end of the experiment for the determination of organic matter, it was seen that the solution color was light yellow. According to this result, it can be said that there is no problem in the perlite aggregate in terms of organic matter that will have a harmful effect on the concrete. The water absorption rate of the perlite aggregate varies depending on the particle diameter. As the grain diameter increased, the water absorption rate also increased. The reason for this is that the amount and volume of voids in the light coarse aggregate is high. The maximum water absorption rate measured in perlite aggregate is 7.2% as seen in Table 4. The water absorption rate of lightweight aggregates to be used in the production of structural concrete should not be more than 15% (Short and Kinniburg,1978; Hossain, 2004; Neville, 1996; Öztaş, 1993; Zhang and Gjorv, 1991; Postacıoğlu, 1987; Kirca, 2018; Thienel et al.2020; Domagala 2015; Liu et al.2011). The water absorption values found were below the recommended limit values. According to the findings, it has been seen that Erzincan molla village raw perlite aggregate can be used as a structural lightweight concrete aggregate in terms of chemical and physical properties and does not contain internal and external harmful substances that will cause negative results in concrete. In the study, it was found that 1.15 m^3 of raw perlite aggregate is required for the production of 1m^3 of fresh concrete.

Figure 2:
Fracture surface after compressive test

As seen in Figure 2, after the samples were broken, when the fracture surfaces were examined, it was seen that there was a strong adherence between the aggregates and the cement paste, and the breakage occurred by shearing the coarse aggregates

Table 4. Physical properties of Erzincan Mollaköy raw perlite aggregate

Properties	Sieve spacing (mm)				
	12.5-9.5	9.5-6.75	6.75-4.75	4.75-1.2	1.2-0
Loose unit weight (kg/m^3)	940	945	950	1040	1100
Compact unit weight (kg/m^3)	1020	1090	1130	1195	1260
Specific gravity (gr/cm^3)	1.91	1.93	1.96	1.99	2.01
Water absorption (%)	7.2	6.6	6	4.5	2.7
Water absorption in 30 minutes (%)	3.4	3.2	2.8	2.2	1.8
Organic materials	-	-	-	absent	absent

In this study, mixtures with slump values of 70 and 120 mm were prepared, and their compression factor test results were found to be 0.85 and 0.90, respectively. As seen in Figure 3, it is seen that there is a decrease in the compressive strength with an increase in the slump value. In this study, it has been observed that the slump value of 70 mm is sufficient for mixing, transporting and placing the concrete in the molds without gaps, and segregation does not occur in the concrete during mixing, transportation and placement. The slump value of 120 mm was easier to mix, transport and place than the slump value of 70 mm, and no segregation was observed during these processes, but a decrease in the cohesiveness of the concrete was observed. With the increase of the slump value, there was a significant decrease in the compressive strength of the concrete and an increase in the water absorption rate as seen in Table 5. The compressive strength of lightweight concretes increases with the increase of cement content as in normal concretes (Erdoğan, 2003; Newman and Owens 2003; Short and Kinniburg,1978; Hossain, 2004; Neville 1996; Kayali et al.2003; Zhang and Gjorv, 1991; Shannag 2011).

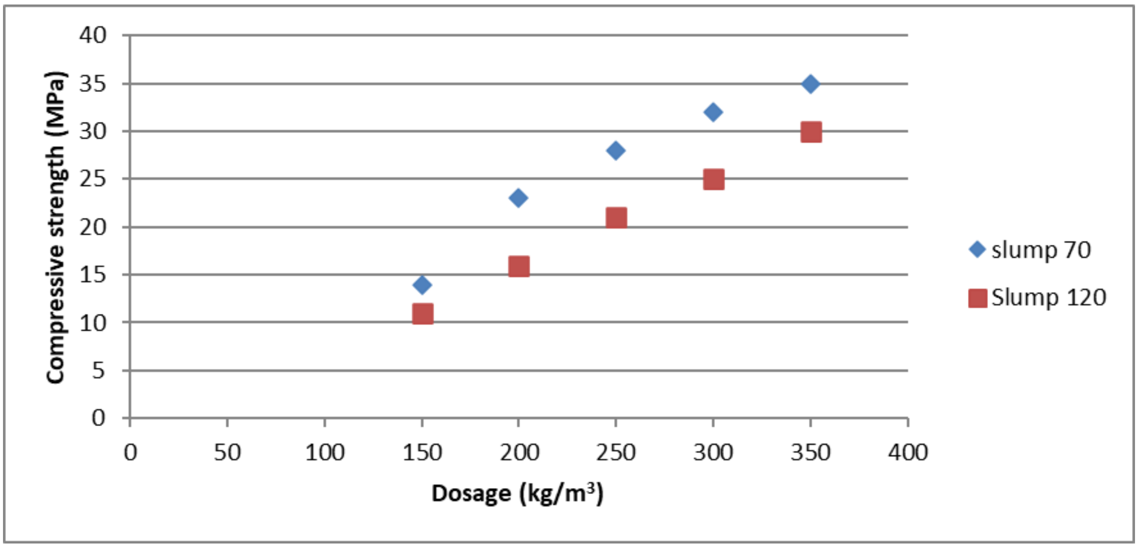

Figure 3:
Changes in compressive strength according to dosage and slump values after ninety days of curing.

In this study, the effect of the increase in dosage on the compressive strength and at which dosage sufficient strength can be obtained were investigated by making mixtures at different dosages. As seen in Figure 3, the compressive strength increased with increasing dosage. The reasons for this increase are the strength of the cement is greater than the strength of the lightweight aggregate and the surface and near-surface spaces of the lightweight aggregate are filled with cement matrix to increase the strength of the lightweight aggregate and the adherence between the aggregate cement matrices. In this study, it was found that 200 kg/m³ of cement was sufficient for a slump of 70 mm and 250 kg/m³ for a slump of 120 mm to produce structural lightweight concrete using raw perlite aggregate after 90 days of curing, as shown in Figure 3. Similar results have been found by other researchers. Researchers such as Neville (1996), Short and Kinniburgh (1978), Shannag(2011), Newman and Owens (2003), Numan et al.2019, Kim et al. 2012 state that a cement of 260-330 kg/m3 is required to produce lightweight concrete with a compressive strength of 20 MPa. Concrete strength increases over time and this increase takes about 90 days, but 95% of the strength is completed in 28 days (Aitcin 1998; Erdoğan, 2003; Neville, 1996). As seen in Figure 4 in this study, increases in compressive strength continued after 28 days, but the increase was greater at high doses and less at low doses. This rate of increase has risen to 24% at a rate of 70 slump and 350 kg/m^3.

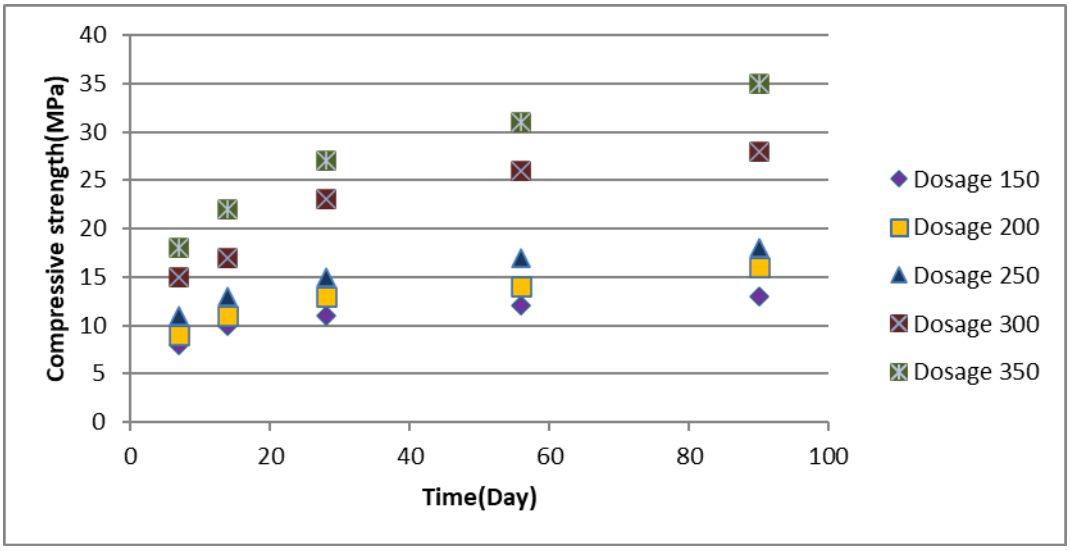

Figure 4:
Variation of compressive strength according to dosage and time

One of the most important advantages of lightweight concrete is the lightness it provides in unit volume. Since the specific gravity of the cement is greater than the specific gravity of the aggregate, the unit weight increases with the increase in the amount of cement.

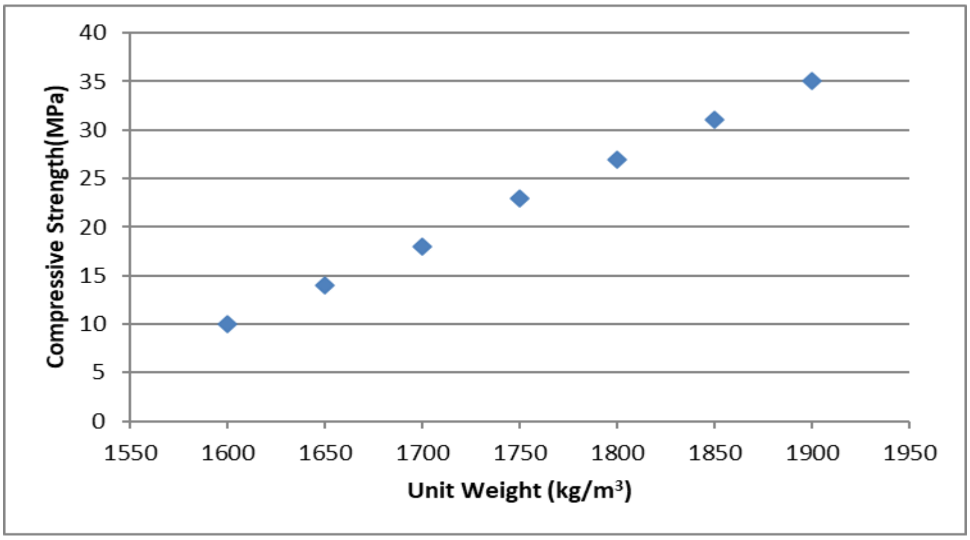

Figure 5:
The relationship between unit weight and compressive strength after 90 days of final curing.

Unit volume weights of structural lightweight concretes vary between 1700 and 1900 kg/m^3. As can be seen in Figure 5, the concrete produced using raw perlite aggregate is in the class of structural lightweight concrete in terms of unit weight. If the unit weight of normal concrete is accepted as 2400 kg/m^3, a decrease of 20-29% in unit weight is achieved. This will provide a reduction in both the earthquake load that will affect the structure and the dimensions of the building elements. As with other lightweight concretes, the compressive strength in this study varies with unit weight. Gamphir (1986), Postacıoğlu (1987), Short and Kinniburgh (1987), Neville (1996), Shannag (2011), Newman and Owens (2003), Damagala 2015, Liu et al.2011 and others state that the water absorption rate of concretes should be below 10% in terms of durability and strength. They state that concrete with high water absorption rates have low resistance to freeze-thaw and chemical effects. The water absorption rates of concrete depend on the aggregate used in the production of concrete, the structure of the cement paste, the degree of compaction of the concrete and the maintenance of the concrete (Aitcin, 1998; Erdoğan, 2003; Short and Kinniburg,1978; Newman and Owens 2003; Damagala 2015; Liu et al.2011; Hossain, 2004; Neville 1996, Kayali et al.2003; TSE2511,2017).

Table 5. Water absorption rate of raw perlite aggregate concrete

Dosage (kg/m^3)		Water absorption rate (%)					
		1/2 hour		24-hour		48-hour	
		Slump 70	Slump 120	Slump 70	Slump 120	Slump 70	Slump 120
150		3.90	4.80	11.50	12.00	12.10	12.40
200		3.20	4.50	10.30	10.50	10.80	11.30
250		3.10	4.30	9.20	9.60	9.80	10.50
300		3.00	4.20	9.10	9.50	9.30	9.70
350		2.80	3.80	8.10	9.10	8.22	9.40

As seen in Table 5, the water absorption rates of the concrete obtained in this study decreased with the increase in dosage and decrease in the slump value. In high dosage samples, the water absorption rate is below 10% and this is because the water absorption rate of the cement matrix is lower than the light aggregate and the majority of the pores of the lightweight aggregate are closed with cement grout to prevent excessive water absorption of the aggregate in the concrete.

The tensile strength of concrete depends on the tensile strength of the cement and aggregate used in the mixture and the adherence between the aggregate and the cement matrix. The porous structure in lightweight aggregates causes the tensile strength of these aggregates to be lower than normal aggregates, therefore the tensile strength of concrete produced using this aggregate will be lower (Chandara and Berntsson, 2003; Erdoğan, 2003; Short and Kinniburgh, 1978; Neville, 1996; Malhotra,1990; Holm and Ries, 1994; TSE 2511, 2017; Wu et al.2019). The tensile strength of concrete is approximately 10% of its compressive strength (Aitcin 1998; Chandara and Berntsson, 2003; Short and Kinniburgh, 1978; Neville, 1996; Kayali et al. 2003; TSE 2511, 2017). Gamphir (1986) states that the tensile strengths and compressive strengths of lightweight concrete vary between 15% and 20%. In this study, the samples prepared at various doses were subjected to the tensile test and the obtained values are given in Table 6.

Table 6. Relationship between compressive strength and tensile strength after 28 days of curing.

	Dosage (kg/m^3)				
	150	200	250	300	350
Compressive strength (MPa)	12.3	20.6	26	29.6	32
Tensile strength (MPa)	1.3	2.25	2.6	3.21	3.53

According to the results obtained, the tensile strength of lightweight concrete with raw perlite aggregate was found to be 11% of the compressive strength.

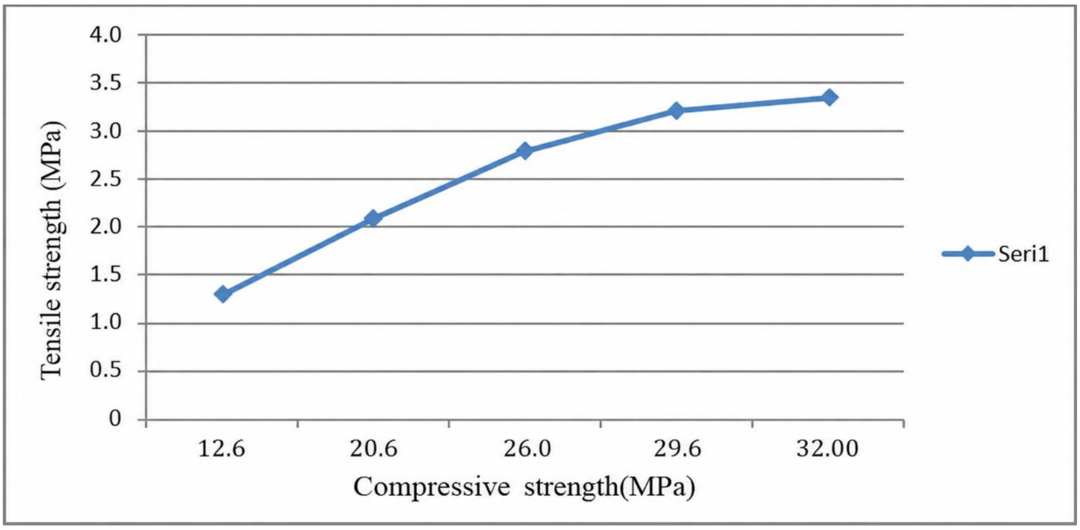

Figure 6:

The relationship between compressive strength and tensile strength after 28 days of curing.

As seen in Figure 6. there is a linear relationship between tensile strength and compressive strength. Tensile strength increased at the rate of increase in compressive strength.

Based on the values obtained from compressive strength tests performed on 100 mm x 100 mm x 100 mm, 150 mm x 150 mm x 150 mm cube and 100 mm x 200 mm cylinder specimens after 90 days of curing, it can be stated that the conversion of a 100 mm cube to a 150 mm cube can be done using Formula 2, and the conversion of a 150 mm cube to a cylinder can be done using Formula 3.

$$f_{cu} = 0.83 * f_c + 3.2\ MPa \tag{2}$$

$$f_{cy} = 1.0153 * f_c - 2.2\ MPa \tag{3}$$

These empirical formulas are quite similar to the conversion coefficients proposed by Hossain (2004) and Neville (1996).

The summary of the study can be outlined as follows:

* It was observed that the compacted unit weight of the aggregate varied between 1020-1260 kg/m^3 depending on the particle size distribution, decreasing as the particle size increased and increasing as the particle size decreased.

* It was observed that the water absorption rate of the aggregate varied between 7.2% and 2.7% depending on the particle size distribution, and that the water absorption rate increased as the particle size increased and decreased as the particle size decreased.

* After a 90-day curing period, it is possible to produce structural lightweight concrete with a slump of 70 mm using 200 kg/m^3 of cement and a slump of 120 mm using 250 kg/m^3 of cement.

* It is possible to produce structural lightweight concrete with a cement content of 350 kg/m^3 and a slump value of 70 mm, and a compressive strength of 35 MPa after a 90-day curing period.

* The unit weight of the produced structural lightweight concrete ranged between 1700 and 1900 kg/m^3.

* Assuming that the unit weight of normal concrete is 2400 kg/m^3, it has been observed that a reduction in unit weight of 20-29% can be achieved.

* It was determined that the tensile strength of the produced structural lightweight concrete was approximately 11% of its compressive strength.

5.2. Recommendations

1- Using mineral additives, the effects of mineral additives on the physical and mechanical properties of concrete should be investigated.
2- By adding steel or polymer fiber, the effects of fiber on the mechanical properties of concrete should be investigated.
3- Concrete should be produced using high amount of binder, the effect of binder amount on physical and mechanical properties of concrete should be investigated.
4- By using super plasticizer, the mechanical and physical properties of concretes with minimum water/b ratio should be investigated
5- The studies should investigate freeze-thaw and sulfate resistance.

CONFLICT OF INTEREST

There is no conflict of interest between the authors.

AUTHOR CONTRIBUTION

İsmet ULUSU contributed to the determination of the conceptual and/or design processes of the study, conducted data collection, data analysis, and interpretation, contributed to the preparation of the manuscript draft, and approved the final version of the study, taking full responsibility for its content.

Rüstem GÜL contributed to the management of the conceptual and/or design processes of the study, participated in the preparation of the manuscript draft, and contributed to the critical review of the intellectual content, and approved the final version of the study, taking full responsibility for its content.

REFERENCES

1. A. Short, W. Kinniburgh (1978) Lightweight concrete Thired Edition. Applied Science Publishers LTD, London.
2. Aïtcin, P. C. (1998) High performance concrete. CRC press.
3. Annual Book of ASTM standarts (1995) Concrete and aggregate. Philadelphia.
4. ASTM C29/C29M-07. Standard Test Method for Bulk Density ("Unit Weight") and Voids In Aggregate.
5. ASTM C330/C330M-17a (2022) Standard Specification for Lightweight Aggregates for Structural Concrete.
6. ASTM C39 /C39M. Standard Test Method for Compressive Strength of Cylindrical Concrete Speciments.
7. ASTM E 11, American Standard Test Sieve Series

8. Badarloo, B., Kari, A., & Jafari, F. (2018) Experimental and numerical study to determine the relationship between tensile strength and compressive strength of concrete. *Civil Engineering Journal*, 4(11), 2787-2800. https://doi.org/10.28991/cej-03091198
9. Bremner, T. W., & Holm, T. A. (1995) High Performance Lightweight Concrete--a Review. *Special Publication*, 154, 1-20. https://doi.org/10.14359/947
10. Chen, B., & Liu, J. (2005) Contribution of hybrid fibers on the properties of the high-strength lightweight concrete having good workability. *Cement and Concrete Research*, 35(5), 913-917. https://doi.org/10.1016/j.cemconres.2004.07.035
11. Domagała, L. (2015) The effect of lightweight aggregate water absorption on the reduction of water-cement ratio in fresh concrete. *Procedia Engineering*, 108, 206-213. https://doi.org/10.1016/j.proeng.2015.06.139
12. Erdoğan, T. Y., & Çimentolar, B. O. M. (1995) Türkiye Hazır Beton Birliği.
13. Ersoy, U (1987) Betonarme temel ilkeler ve taşıma gücü hesabı (Cilt1-2). *Evrim basım-yayın dağıtım*, İstanbul.
14. Ersoy, U. (2013) A simple approach for preliminary design of reinforced concrete structures to be built in seismic regions. *Teknik Dergi*, 24(120), 1701-1716. https://izlik.org/JA47GH28CR
15. Faust, T., & Konig, G. (1998) High strength lightweight aggregate concrete. In Proceedings 2nd International Ph. D. Symposium in Civil Engineering (p. 8). *Technical University of Budapest*.
16. Gambhir, M.L(1986) Concrete Technology, Tata McGraw- Hill Publishing Company Limited, New Delhi.
17. Halit Demir(1993) Investigations and Princibles Concerning Building Damges due to Earthquakes. *2. Ulusal Deprem Mühendisliği konferansı*
18. Hoff, G. C. (1990) High-strength lightweight aggregate concrete—current status and future needs. In High-Strength Concrete Second International Symposium; *ACI Special Publication; ACI: Berkeley*, CA, USA (pp. 121-130).
19. Holm, T. A., & Ries, J. P. (1994) Lightweight concrete and aggregates. In Significance of tests and properties of concrete and concrete-making materials (pp. 548-560). ASTM International.
20. Hossain, K. M. A. (2004) Properties of volcanic pumice based cement and lightweight concrete. *Cement and concrete research*, 34(2), 283-291. https://doi.org/10.1016/J.CEMCONRES.2003.08.004
21. Kayali, O., Haque, M. N., & Zhu, B. (2003) Some characteristics of high strength fiber reinforced lightweight aggregate concrete. *Cement and concrete composites*, 25(2), 207-213. https://doi.org/10.1016/S0958-9465(02)00016-1
22. Kim, H. K., Jeon, J. H., & Lee, H. K. (2012) Workability, and mechanical, acoustic and thermal properties of lightweight aggregate concrete with a high volume of entrained air. *Construction and Building Materials*, 29, 193-200. https://doi.org/10.1016/j.conbuildmat.2011.08.067
23. Kirca, Ö. (2018) Ancient binding materials, mortars and concrete technology: history and durability aspects. *Structural Analysis of Historical Constructions; Modena*, C., Lourenço, PB, Roca, P., Eds, 87-95. https://www.scribd.com/document/387387688
24. Malhotra, V. M. (1990) Durability of concrete incorporating high-volume of low-calcium fly ash. *Cement and Concrete Composites*, 12(4), 271-277. https://doi.org/10.1016/0958-9465(90)90006-J
25. Nadesan, M. S., & Dinakar, P. (2017) Mix design and properties of fly ash waste lightweight aggregates in structural lightweight concrete. *Case studies in construction materials*, 7, 336-347. https://doi.org/10.1016/j.cscm.2017.09.005
26. Neville A.M (1996) Properties of Concrete. *John Wiley & Sons*, New York.

27. Newman, J., & Owens, P. (2003) Properties of lightweight concrete. *Advanced concrete technology,* 3, 1-29. https://doi.org/10.1016/B978-075065686-3/50288-3

28. Novokshchenov, V., & Whitcomb, W. (1990) How to obtain high-strength concrete using low-density aggregate. *Special Publication*, 121, 683-700.

29. Numan, H. A., Yaseen, M. H., & Al-Juboori, H. A. M. S. (2019) Comparison mechanical properties of two types of light weight aggregate concrete. *Civil Engineering Journal*, 5(5), 1105-1118. http://dx.doi.org/10.28991/cej-2019-03091315

30. Postacıoğlu B (1987) Beton Cilt 2, Matbaa Teknisyenleri Basımevi İstanbul.

31. S Chandara, L Berntsson (2003) Lightweight Aggregate Concrete. Noyes Publications, New York U.S.A

32. Shannag, M. J. (2011) Characteristics of lightweight concrete containing mineral admixtures. *Construction and Building Materials*, 25(2), 658-662. http://dx.doi.org/10.1016/j.conbuildmat.2010.07.025

33. Surahyo, A., Surahyo, L., & Luby. (2019) Concrete construction (pp. 61-88). *Springer International Publishing*.

34. Thienel, K. C., Haller, T., & Beuntner, N. (2020) Lightweight concrete—From basics to innovations. *Materials,* 13(5), 1120. https://doi.org/10.3390/ma13051120

35. TSE 2511 (2017) Taşıyıcı Hafif Betonların Karışım Hesap Esasları, Türk Standartları Enstitüsü, Ankara.

36. Turgut Öztaş (1993) General Enginering Geological Properties of Erzincan. *2. Ulusal Deprem Mühendisliği konferansı.*

37. Turhan Y. Erdoğan (1995) Betonu Oluşturan Malzemeler Agregalar, *Türkiye Hazır Beton Birliği*, Ankara

38. Turhan Y. ERDOĞAN (2003) BETON. *ODTÜ Yayancılık*, Ankara.

39. Zhang, M. H., & Gjorv, O. E. (1991) Characteristics of lightweight aggregates for high-strength concrete. *Materials Journal,* 88(2), 150-158. https://www.researchgate.net/publication/250613861_Characteristics_of_lightweight_aggregates_for_high-strength_concrete

40. Wu, T., Yang, X., Wei, H., & Liu, X. (2019) Mechanical properties and microstructure of lightweight aggregate concrete with and without fibers. *Construction and Building Materials,* 199, 526-539. https://doi.org/10.1016/j.conbuildmat.2018.12.037