Sürdürülebilir Mühendislik Uygulamaları ve
Teknolojik Gelişmeler Dergisi
2021, 4(2): 88-97

Perlitin Dünyada ve Türkiye'de Çimento ve Beton Sistemlerinde Kullanımı

The Use of Perlite in Cement and Concrete Systems in the World and Turkey

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Doi: 10.51764/smutgd.987973

Geliş Tarihi : 27.08.2021
Kabul Tarihi : 05.10.2021

ÖZET

Küresel ısınma nedeniyle birçok sektör sürdürülebilir yöntemler keşfetti. Karbon salınımını azaltmak için birçok sektörde birçok çalışma yapılmıştır. İnşaat sektöründe çimento üretimi büyük miktarda karbon salınımına neden olmakta ve bu duruma son vermek için Portland çimentosu ile üretilen beton yerine yeşil beton adı verilen puzolan katkılı beton kullanılmaya başlanmıştır. Bu yeşil betonların üretiminde kullanılan malzemelerden biri de perlittir. Bu çalışma perlit madeninin literatür taramasıdır. Perlit madeninin dünyadaki ve Türkiye'deki durumu araştırılmıştır. Deneysel çalışmaların sonuçlarına göre perlitin yapay puzolanın yerine nasıl kullanılabileceği, inşaat sektörüne hangi aşamalarda hazır hale getirildiği ve ülkemiz için neden büyük önem taşıdığı açıklanmaya çalışılmıştır.

Anahtar Kelimeler: Perlit, doğal puzolan, perlit rezervleri, Türkiye'de perlit, perlit tozu.

ABSTRACT

Due to global warming, many sectors have discovered sustainable methods. Many studies have been conducted in various sectors to reduce carbon emissions. Cement production in the construction sector causes an enormous carbon emission, and to put an end to this situation, pozzolan-added concrete, which is called green concrete, has been put into use instead of concrete produced with Portland cement. One of the materials used in the production of these green concretes is perlite. This study is a literature review of the perlite mine. The situation of perlite mines in Turkey and the world has been researched. According to the results of experimental studies, it has been tried to explain how perlite can be used as a substitute for artificial pozzolan, at what stages it is made ready for the construction sector, and why it is of great importance for our country.

Keywords: Perlite, natural pozzolan, reserves of perlite, perlite in Turkey, perlite powder.

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INTRODUCTION

Perlite is a rock that reaches up to twenty times its volume when expanded, is light in its expanded form, and provides heat and sound insulation. Turkey has 74% of the possible perlite reserves in the world. In the world and Turkey, the most common use of perlite is seen in the construction sector. For this reason, perlite consumption in the world is highly affected by the fluctuations in the construction sector. Perlite has significant advantages compared to cement in terms of heat insulation, sound insulation, and earthquake resistance, and for this reason, the use of perlite in the construction sector will make significant contributions to the country's economy. Concrete; consists of chemical additives to be added depending on the desired properties of cement, aggregate, water, and concrete. Chemical additives can be used to give concrete some wanted properties, but aggregates used at a rate of 60-85% are the components that most affect the characteristic properties of concrete. The unit weight of the concrete may vary depending on the characteristics of the aggregate used. Thus, lightweight concrete can be producible. Advantages of lightweight concrete over regular concretes; can be listed as reducing dead loads in the building, earthquake resistance, providing high heat and sound insulation among the light concretes produced using light aggregates. Perlite-added concrete ensures that about ten times better thermal insulation compared to regular concrete. Light building materials with perlite additives reduce greenhouse gas waste by increasing energy efficiency and are therefore called environmentally friendly materials. Heat insulation will provide, energy savings will achieve in buildings where perlite added concrete is used. This factor is significant for our country that imports energy from abroad. Thanks to energy savings, contributes to the country's economy. Heat insulation will provide, energy savings will achieve in buildings where perlite added concrete is used. This factor is significant for your country that imports energy from abroad. Thanks to energy savings, contributes to the country's economy. (Duaij, 1997).

Perlite

Perlite is heated suddenly to a suitable temperature very light and porous; it is a pearly luster, acidic volcanic glass. Perlite is not a mineral, it is a rock. The word perlite is derived from the word "Perle" which means pearl. This name is given because some perlite types become small spheres when broken. Expanded perlite is the name of the last state in which raw perlite has come to some processes. In addition, volcanic glasses that contain water such as "obsidian" or "pitchstone" and expand when heated can be called perlite. The recognition and industry of perlite are new. It was first observed in Germany in 1925 that perlite expanded when heated. However, no serious studies have been conducted on this subject for many years. Expanded perlite was invented in 1940 in Arizona. The perlite industry started to develop essentially after 1947. This development in America later pioneered the establishment of this industry in Western Europe and Japan.

Raw Perlite

Raw perlite is the name given to the rock formations of perlite before it is processed. The most significant feature of raw perlite is water that provides stability and is in the form of silica at 2.5% (D.P.T, 2001).

Figure 1 Raw Perlite

Expanded Perlite

Raw perlite goes through the grinding process before being subjected to 400 degrees. After these processes, perlite subjected to high heating (750 ° C -1200 ° C) expands with the steam effect and forms a glass-like foam aggregate. It expands up to 20 times its volume and becomes white after expand. It is called expanded perlite. (D.P.T, 2001).

Figure 2 Expanded Perlite

Perlite Chemical Composition

Perlite is a material that contains water, has a specific texture, and is acidic volcanic glass. Free of heavy metals, radioactive elements, and organic matter. It is very pure in chemical terms. Chemical compositions of perlite are given in table 1 (D.P.T, 2001).

Table 1 Perlite chemical compositions

Chemical Composition	Amount
SiO_2	71.0-75.0
Al_2O_3	12.5-18.0
Na_2O_3	2.9-4.0
K_2O	0.5-5.0
CaO	0.5-2.0
Fe_2O_3	0.1-1.5
MgO	0.02-0.5
TiO_2	0.03-0.2
H_2O	2.0-5.0
MnO_2, FeO, Cr	0.0-0.1
Ba	0.0-0.05
PbO	0.0-0.03
NiO, Cu, B, Be	Very Little
SO_3	0.0-0.2

Perlite Physical Properties

Perlite has a glassy structure and can decompose into small pieces. Raw perlite breaks easily because it has a fine-grained, porous structure. Perlite can be classified as follows according to its appearance and texture. Pumice, granular, concentric structured, and fibrous perlite. Physical properties of perlite are given in table 2 (Azizi, 2007), (M.T.A, 1985).

Table 2 Perlite Physical Properties

	Raw Perlite	Expanded Perlite
Color	Grey, Shades of grey and black	White, shades of grey
Softening Point	800-1100 °C	871-1093 °C
Melting Point	1315-1390 °C	1260-1343°C
pH	6,6-8	-
Hardness	-	5-6 Mohs
Specific Heat	0,2kcal/kg°C	0,2cal/g°C
Specific Weight	2200-2400kg/m3	-
Thermal Conductivity	-	0.04W/Mk
Dissolution in Acid	Hot concentrated alkali, in mineral, concentrated acids While it melts a little, dilute mineral or concentrated little in weak acids they melt.	Hot concentrated alkali and soluble in hydraulic acid, mineral little in concentrated acids, dilute mineral or concentrated They dissolve very little in weak acids.

Perlite Mineralogical Composition

90–97% of its volume is glass, and the crystallized minerals are feldspar and biotite. Rarely, apatite and magnetite are seen. Dough, often made of volcanic glass it contains microliths and phenocrysts. Despite the glass character of perlite, fine cracks detect in the onion-skin structure.

The refractive index of perlite is between 1.488 and 1.506, with an average value of 1,497. In polarized light, perlite glass is isotropic; but sometimes a slight birefringence is shown. According to X-ray analysis (XRD), perlites contain up to 4% free silica detected. In altered perlites; chalcedony, opal, montmorillonite, and ilmenite minerals can be found. But in unaltered perlites do not contain secondary minerals.

EXPERIMENTAL STUDIES REVIEW

Perlite Powder in Concrete and Its Effects

In an experimental study, it was tried to reduce the alkali-silica reaction by using perlite powder. In an experimental study, it was tried to reduce the alkali-silica reaction by using perlite powder. Mortar samples include specific amounts of silica fume, expanded perlite, and raw perlite. During the study, two different types of aggregates were used. These are called highly reactive river aggregate and reactive monzodiorite. These two samples that contain silica fume and expanded perlite separately, were tested with monzodiorite and river aggregate.

According to the ASTM C 1260, three procedures were done. First, the mortar samples were poured into a stick mold, then kept in NaOH solution for 30 days, and finally, the change in length of the samples was observed. The tests, which proceed in two different stages, were tested as perlite powder and silica fume samples in the first stage and as raw perlite additive in the second stage. Test results compared. According to the results of the studies, it is seen that when raw perlite or expanded perlite is included in the samples, it triggers the alkali-silica reaction and suppresses the expansion. Looking at the results of the experiments on raw perlite and expanded perlite, it is seen that expanded perlite is more resistant to alkali-silica reaction compared to raw perlite.

It determined that there are not enough studies on perlite in the literature. It emphasized that experimental studies should increase. (Turanlı L. B., 2004).

Fibre-Reinforced Semi-Lightweight Concrete with Unexpanded Perlite

In a study carried out in the METU Materials Mechanics Laboratory, a fiber-reinforced lightweight concrete sample was prepared for seismic reinforcement in reinforced concrete structures and lightweight concrete properties were investigated. The samples containing 35% unexpanded perlite were subjected to tests as steel fiber reinforced and polypropylene added.

Samples of unexpanded perlite and fiber-free concrete also were tested. It has been tested samples without fiber additive and unexpanded perlite additive.

As a result of the experimental studies, considering the 28-day compressive strength, it was observed that the lightweight concrete with unexpanded perlite was more effective than the concrete sample made of ordinary Portland cement and had lower tensile strength and modulus of elasticity. It observed that the specimen with unexpanded perlite decreases the load and energy capacity and affects the bending strength of the panels. As a result, fiber samples with perlite and fiber specimens without perlite were observed, and that the specimens with perlite were more advantageous with their results. (Turanlı L. O., 2011).

High Volume Additive Natural Pozzolans

In an experimental study, some experiments were carried out on 3 different concrete samples. Fly ash, blast furnace slag, pozzolanic additives were added to the concrete samples.

The values were obtained as a result of the experiments examined. Setting time, compressive strength, chloride ion values were discussed. Perlite, zeolite and volcanic tuff were mixed as 50% natural pozzolan and 50% cement. Likewise, a concrete specimen obtain by mixing fly ash and blast furnace slag with 50% cement, and these five different samples compared each other with the reference concrete sample made with 100% Portland cement.

In the literature, natural pozzolans are found in concrete at a rate of 30% or less. The most important feature of this study is the high amount of natural pozzolans in concrete and results are discussed. According to the results of the studies, perlite and blast furnace slag had less pressure resistance in 28 days compared to the others. However, on the 91st day, the sample prepared only with perlite has passed the pressure extension of the other samples. In addition, in this study, was understood that the high amount of natural pozzolan samples did not remain behind the specimens with a high amount of fly ash and high furnace slag, and could be used instead of artificial pozzolan when necessary. (Mehta, 2007).

Lightweight Concrete Durability with Perlite Aggregate Additive

Concrete strength investigated that 0-20% weight expanded perlite additive concrete. The sample was stored in an environment that would be exposed to chlorine and its durability tested. Instead of Portland cement, 50% blast furnace slag and 7% silica fume were used. Strength of concrete, unit weight, drying shrinkage, chloride permeability, compressive strength, bending strength, the resistance of concrete against steel corrosion were investigated as mechanical properties. Most importantly, the thermal insulation feature was defined. It is clear from the results of all experiments that; Perlite added concrete is 20-30% lighter in weight than concrete produced from Portland cement.

When compressive strength compares, it was found sufficient. A concrete sample containing 10-15% perlite aggregate was more successful in seismic loading tests than concrete produced from regular Portland cement. The biggest difference was in thermal insulation. The thermal insulation of concrete produced from perlite aggregate is much higher than that of normal concrete. (Ibrahim, 2020).

Experimental Studies Results

The conclusions to be drawn from the summaries of the experimental studies given above can be listed as follows.

• Concretes made with expanded perlite show more effective performance in alkali-silica reactions than those made with raw perlite. Although the perlite reserves in our country constitute 3/4 of the world, Turkey follows the policy of selling its raw perlite reserves without expanding them. This situation should be reversed and the extracted raw perlite products should be expanded in our own country used within itself and sold the surplus.

• According to the results of the fibrous concrete with perlite additive's tests, the compressive strength values of 7 and 28 days are given. The values are as follows; (Turanlı L. O., 2011).

Table 3 Test Values

Properties	Compressive Strength	Modulus of Elasticity	Splitting Tensile Strength	
Day	7	28	28	28
SLC	35	36.4	14.0	3.06
SLC-P	31.5	52.2	10.4	2.53
SFRLC	36.0	37.9	13.5	5.67
SFRLC-P	26.8	44.7	9.1	4.23
PFRLC	31.9	35.2	14.9	4.28
PFRLC-P	28.7	52.8	9.2	3.85

• Definition of abbreviations given in table 4 (Turanlı L. O., 2011).

Table 4 Definitions of Abbreviations

Abbreviation	Definition
SLC	Semi-lightweight concrete
SLC-P	Semi-lightweight concrete with 35% unexpended perlite powder replacement
SFRSLC	Steel-fibre-reinforced semi-lightweight concrete
SFRSLC-P	Steel-fibre-reinforced semi-lightweight concrete with 35% unexpended perlite powder replacement
PFRSLC	Polypropylene-fibre reinforced semi-lightweight concrete
PFRSLC-P	Polypropylene-fibre reinforced semi-lightweight concrete with 35% unexpended perlite powder replacement

• According to the results, when the 7-day and 28-day compressive strengths are compared, the unexploded perlite added concrete samples show less performance at the 7-day compressive strength than the non-additive concrete, while the 28-day compressive strength increases considerably compared to the regular concrete. When the concrete is ready for use, the compressive strength of the unexploded perlite added concrete is much better than concrete without additive perlite. Considering only the compressive strength, the unexploded perlite additive of the concrete increased the strength very well rather than the steel fiber and polypropylene fiber. Considering the modulus of elasticity and split tensile strength, perlite additive decreased these two values.

• In the study of the use of perlite aggregate in lightweight concrete, the weight of the concrete sample using perlite aggregate was reduced compared to the traditional concrete, it gave better results in the loading test than the conventional concrete, and most importantly, the perlite-added concrete was ahead with a big difference in thermal insulation.

• As a result of all these experiments, the importance of using perlite as a sustainable material in the construction sector was emphasized. In the light of this, the use of perlite in the world and Turkey and the importance of Turkey in perlite will be mentioned.

USAGE AREAS OF PERLİTE İN CONSTRUCTİON INDUSTRY

Lightweight Concrete Production

In a study conducted in the building materials branch of the METU civil engineering department, 3 different samples were prepared. These are; raw perlite aggregate carrier lightweight concrete, raw perlite aggregate and perlite dust, self-compacting carrier lightweight concrete, and limestone aggregate regular weight carrier concrete. In the experiments performed, CEM I 42.5 R type cement, perlite aggregate with 0-12 mm grain size, was used to pass through 45 microns. Ground perlite powder, 0-25 mm limestone aggregate was used. The samples were determined by pozzolanic activity, alkali-silica reactivity, freeze-thaw effect, acid, resistance to sulfate, and carbonation effect subjected to tests. Unit weight in results 2393 kg / m^3 limestone aggregate bearing concrete instead, the unit weight is 1935 and 1970 kg / m^3 the one which raw perlite aggregate carrier lightweight concrete found to be suitable for the purpose.

Lightweight concrete in TS 2511 standard; air-dried unit weight 1900 kg/m^3 less than and compressive strength at least 160 kgf /cm^2 (16 MPa) as concrete is defined. American Concrete Institute (American Concrete Institute-ACI) about bearing lightweight concrete in the committee report No. 213, bearing lightweight concrete; lightweight aggregate 28-day air dry unit weight obtained using usually 1440-1850 kg /m^3 and compressive strength 17 it is defined as concrete above MPa. In general practice unit weights, about 1600-1750 kg /m^3 lightweight concrete mixes are used. The use of load-bearing lightweight concrete is preferred in buildings because they reduce the total cost of the building. Although the unit volume price of lightweight concrete is higher than the unit volume price of normal concrete, it is more affordable because the dead loads in the building are reduced.

Raw Perlite in Concrete Tile

The process in the production of raw perlite added tiles is as follows; raw perlite (0.5-1.5 mm) is mixed with cement and water at a ratio of 2:1, after pouring into molds. Then it is subjected to curing at 40-50 ° C for 8-9 hours.

M.E.T.U Civil Engineering Department Rotation-dissolution strength studies were carried out in the Materials Division. Contrary to expectations, there is no difference in breaking loads under the effect of bending between -25 and +36 ° C. No decrease was observed, strangely by 26% and 33% respectively increase was observed. In the last tests carried out at -40 ° C, the increase in strength increased to 35%. Due to its high thermal insulation properties, perlite tile is ideal for regions with very hot and very cold climates.

Perlite in Aerated Concrete and Pumice Block Production

As defined in TS 825, dry unit weights can change from 600 kg/m^3 to 1200 kg /m^3. Perlite, sand, and cement trio can mix in a suitable environment if want to produce ultra-light panels. Unit volume weight can reduce to 300 kg/m^3. This mix ratio by volume can be one scale perlite, eight scales others. Fiber, gypsum, sodium silicate, or asphalt when using connectors such as eight scales perlite by volume, one scale as high as any can be.

Raw Perlite Aggregate Usability in Asphalt Mixtures

At METU Civil Engineering Department, some laboratory experiments were carried out about the use of raw perlite as aggregate in asphalt mixtures to explore the possibilities. For this purpose, experiments determinations were made in different ratios (100%, 46%) perlite basalt aggregate prepared by mixing the stability, yield, bulk density, and maximum theoretical density. Stability values of mixtures made with perlite aggregate were found higher than stability values of admixtures made with basalt aggregate. The admixture made with 100% perlite has a higher stability value than the 94% mixture of basalt aggregate. 46% perlite-added mixture stability was 30% higher.

Perlite as a Pozzolanic Additive

As a result of the literature review, perlite can use as pozzolanic material. Compared to the fly ash, blast furnace slag, silica fume, and volcanic ashes, perlite minerals could show that compressive strengths are similar when producing concrete with these pozzolanic materials.

In another study, usability-testing of raw perlite by grinding it together with gypsum and clinker. Perlite is ground together with Portland cement clinker and gypsum in certain proportions by weight. Perlite added cement was obtained. Dough prepared with this cement and various physical and mechanical features has been determined. Perlite compared both each other and samples that do not contain perlite in terms of their performances in cement and mortars. According to the strength results obtained raw perlite can use from 5% to 25% for cement, concrete, and mortar production.

Production and Expansion of Perlite

Raw perlite; It is converted into expanded perlite after crushing, grinding, and classification stages. When the raw perlite is crushed next to the furnace and brought to the required grain size, it provides an economic profit. The properties to be considered while preparing perlite are:

- Make raw perlite as cubic pieces as possible.
- Bringing the perlite to the required grain size without damaging, breaking, and making it very fine.

The expansion stages of raw perlite can be listed as follows; To get rid of the water in the ground raw perlite, is cooked at 400 degrees and made ready for blasting. In this case, perlite starts to explode in a very short time. When it reaches a temperature varying between 700-1200 ° C, the water suddenly evaporates and the volume of perlite increases 30 times. It gives perlite a slightly porous and glassy structure (D.P.T, 2001).

Reserves of Perlite

Perlite reserves in the world are available in regions within the volcanic belt. The information that the visible reserve was 700 million tons in 2009 is available in the reports of the U.S Geological Survey. However, it was observed that there were changes in the 2021 reserves in the reports of this organization. The reserve situation of the United States seems unchanged, but it appears that the reserves of other regions have changed.

Table 5 shows the reserve amounts for 2009 and 2021 (U.S. Geological Survey, 2009), (U.S. Geological Survey, 2019).

Table 5 Perlite reserves comparison

	2009 Reserves	2009 Reserve Base	2020 Reserves
United States	50,000	200,000	50,000
Greece	50,000	300,000	120,000
Hungary	3,000	Included with “Other countries.”	49,000
Mexico	Included with “Other countries.”	Included with “Other countries.”	NA
Turkey	Included with “Other countries.”	5,700,000	5,700
Other Countries	600,000	1,500,000	NA
World Total	700,000	7,700,000	NA

Considering the data in the table, the visible reserve in the world is 700 million tons and the total visible and probable reserve is 7700 million tons in 2009. This situation is different according to the data of 2021. Total reserve is shown as “none” in 2021 data. Considering the data in the table, the visible reserve in the world is 700 million tons and the total visible and probable reserve is 7700 million tons in 2009. This situation is different according to the data of 2021. Total reserve is shown as “none” in 2021 data. As can be seen from Table 5, the reserves of Greece and Hungary have changed over the years. It is observed that the reserves of the USA have not changed over the years.

According to the data in 2020, Turkey has got 74% of the world’s perlite reserves with 5.700 million tons. (U.S. Geological Survey, 2009), (U.S. Geological Survey, 2019).

Production and Consumption of Perlite

Perlite production in the world has increased from 2008 to 2020. The average perlite production in 2008 was 1.8 million tons. As a result of China’s participation in production in 2014, this figure was 3.46 million tons in 2019. An estimated perlite production in 2020 is 3.4 million tons. Perlite production rates are predicted in this way for 2020, with China 38%, Turkey 21%, Greece 19%, and America 15%. The production amount in 2008 and 2020 is given in table 6 and the increase in perlite production in Turkey is noteworthy.

Table 6 Perlite productions in 2008 and 2020

Countries	2008	2020
United States	450	520
Greece	500	700
Hungary	70	70
Japan	240	NA
Mexico	45	20
Turkey	270	640
China	NA	1300
Other Countries	200	185
Total	1770	3400

Although China seems to have the largest production, Turkey and Greece share first place in terms of exports. The reason for this is that China consumes what it produces within itself.

Perlite sales in the USA in 2018 were 37 million dollars and its usage was 510 thousand tons. The use of expanded perlite is mostly associated with the construction sector with 58%. These data were obtained according to the U.S Geological survey reports. It is understood from here that perlite is an important material that is widely used in the mine construction industry.

Perlite Industry in Turkey

Looking at the map of perlite reserves of MTA, there is a reserve distribution in almost every region of the country where consumer perlite can easily be reached. Domestic perlite consumption rates are revealed in a study conducted by Turkey IGEMA. According to the results of the research, 60% of domestic consumption is used in the construction sector, 17% in agriculture, 20% in industry, and 3% in other sectors. Figure 3 shows the perlite reserve distribution of turkey.

Figure 3 Perlite reserve regions in Turkey

Perlite export of Turkey increased from 3.3 million USD in 2000 to 25.7 million USD in 2014. Table 7 showing the perlite export of Turkey is given below (Türkiye Madenciler Derneği).

Table 7 Perlite export of Turkey

Year	Thousand Tons	Million Dollar
2009	257	11,5
2010	333	15,8
2011	317	17,6
2012	388	21,5
2013	388	22,5
2014	423	25,7

In Turkey, which is in an earthquake zone, perlite is not given the necessary importance and is not used enough in the construction sector. Perlite is mostly used in modern construction technologies and first-class buildings. For this reason, its use is not widespread. Perlite provides sound insulation and provides 17% iron savings in construction. Perlite is significant because it is abundant in our country. In addition, all countries of the world take fast measures on sustainability and it is very substantial to use perlite material as a sustainable material in the construction sector. It is necessary to increase its use in our country and to carry out the compulsorily experimental studies. (T.C Kalkınma Bakanlığı, 2018).

CONCLUSION AND RECOMMENDATION

Perlite reserves are mostly found in Turkey in the world. 74% of the reserves are in the territory of Turkey. In the production of perlite, our production rate in the world corresponds to 21%. 65% of perlite is used in the construction industry. According to the results of the experimental studies, it can be used as a perlite plaster material; it is also suitable for use in construction as insulation material and as a filling material. Usage rate between 12-16% is appropriate and gives better performance than silica amount of silica fume additive. Since silica fume is difficult and expensive to reach, perlite additive can be used instead of silica fume. Considering the reserve status of Turkey, necessary studies should be done and serious attention should be paid to perlite as it can provide a great advantage to the construction industry.

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