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## **Physical and Mechanical Properties of Different Types of Mortars Produced with Hydrophobic Perlite**

### **Hidroforik Perlit ile Üretilen Farklı Harç Tiplerinin Fiziksel ve Mekanik Özellikleri**

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## Physical and Mechanical Properties of Different Types of Mortars Produced with Hydrophobic Perlite

### ABSTRACT

This study contributes to the limited research in this field by enabling hydrophobic perlite to be used more efficiently in cement and gypsum based lightweight composites by reducing water absorption and explores an innovative approach to increase the hydrophobic properties of expanded perlite by making it hydrophobic. In the first stage, hydrophobic perlite was obtained by grinding expanded perlite together with a liquid chemical agent with hydrophobic properties. This hydrophobic perlite was mixed with cement and gypsum at different water ratios to produce various mortars. The physical properties of the mortars were analyzed in terms of unit weight, water absorption rate by weight, capillary water absorption rate and ultrasonic pulse velocity, while the compressive strength was investigated in terms of mechanical properties. Tests on criteria, such as water absorption test, ultrasonic transmission rate, unit weight and compressive strength revealed that mortars produced with hydrophobic perlite exhibited significantly lower water absorption rates and improved mechanical properties compared to conventional mortars. The findings of the study indicate that hydrophobic perlite is an effective contributor to the production of water-resistant and performance-enhanced building materials. This method offers potential applications in the construction and building industries for the development of mortars and other building materials with enhanced hydrophobic properties.

**Keywords-** *Hydrophobic, perlite, cement, gypsum plaster*

### Highlights

- Hydrophobic perlite was produced using a silane-siloxane-based chemical agent.
- Hydrophobic perlite reduced water absorption and capillary uptake by up to 70%.
- Only about 6% reduction in compressive strength was observed.
- Unit weight remained almost unchanged, ensuring lightweight characteristics.
- The method provides an eco-friendly and economical solution for durable mortars.

## Hidroforobik Perlit ile Üretilen Farklı Harç Tiplerinin Fiziksel ve Mekanik Özellikleri

### ÖZ

Bu çalışma, geliştirilmiş perlitin hidroforobik özelliklerini, onu hidroforobik hale getirerek artırmayı amaçlayan yenilikçi bir yaklaşımı araştırmaktadır. İlk aşamada, geliştirilmiş perlitin hidroforobik özelliklere sahip sıvı bir kimyasal madde ile birlikte öğütülmesiyle hidroforobik perlit elde edilmiştir. Bu hidroforobik perlit, çeşitli harçlar üretmek için farklı su oranlarında çimento ve alçı ile karıştırılmıştır. Harçların fiziksel özelliklerinden birim ağırlık, ağırlıkça su emme oranı, kapiler su emme oranı ve ultrases geçiş hızı özellikleri incelenirken, mekanik özelliklerinden basınç dayanımı araştırılmıştır. Su emilim testi, ultrasonik iletim hızı, birim ağırlık ve basınç dayanımı gibi kriterler üzerinde yapılan testler, hidroforobik perlit ile üretilen harçların, geleneksel harçlara kıyasla önemli ölçüde daha düşük su emilim oranları ve iyileştirilmiş mekanik özellikler sergilediğini ortaya koymuştur. Çalışmanın bulguları, hidroforobik perlitin suya dayanıklı ve performansı artırılmış yapı malzemelerinin üretiminde etkili bir katkıda bulunduğunu göstermektedir. Bu yöntem, inşaat ve yapı endüstrilerinde, hidroforobik özellikleri artırılmış harçlar ve diğer yapı malzemelerinin geliştirilmesi için potansiyel uygulamalar sunmaktadır.

**Anahtar Kelimeler-** *Hidroforobik, Perlit, Çimento, Alçı sıvası*

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## Öne Çıkanlar

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- Hidrofobik perlit, silan-siloksan esaslı bir kimyasal madde kullanılarak üretilmiştir.
  - Hidrofobik perlit, su emme ve kapiler su emme oranlarını %70'e kadar azaltmıştır.
  - Basınç dayanımında yalnızca yaklaşık %6 oranında azalma gözlenmiştir.
  - Birim ağırlık değerleri büyük ölçüde değişmemiş, hafif yapı özelliği korunmuştur.
  - Yöntem, dayanıklı harçlar üretimi için çevre dostu ve ekonomik bir çözüm sunmaktadır.
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## I. INTRODUCTION

Hydrophobic properties play a critical role in the design of construction and building materials [1]. Conventional concrete, plaster and similar building materials are at risk of losing their structural integrity and durability when they come into contact with water [2, 3]. Water can penetrate the porous structure of these materials and cause cracks, deformations and reduced mechanical strength over time [4]. Environmental factors, especially climate change and increased rainfall, can adversely affect the performance of such materials [5]. Therefore, increasing the water repellent properties of materials is of great importance in terms of longevity, safety and reducing maintenance costs of the structure [6]. Furthermore, natural filling materials, such as hydrophobic expanded perlite, not only improve water resistance, but also offer excellent thermal insulation properties [7, 8]. This improves the energy efficiency of structures, keeping indoor temperatures more stable and thus reducing energy consumption, which both increases comfort and contributes to sustainability goals [9-11]. Due to its light weight and insulating properties, expanded perlite is also used for thermal and acoustic insulation in building materials. It is also widely used as an additive in fire resistant coatings, lightweight concrete production, plaster and screed production [12, 13].

There are various usage areas and applications of expanded perlite in the literature. Expanded perlite offers various advantages in the building and construction industry by being developed with different modification and composite methods. Treatment with polydimethylsiloxane emulsion and sodium methyl silicate for hydrophobic modification significantly reduced the water absorption rate, while causing small increases in thermal conductivity and density [14]. The expanded perlite-aerogel composite matrix developed to solve the problems of low thermal stability and leakage of phase change materials is proposed as a carrier that provides high energy efficiency [15]. Furthermore, surface coatings based on expanded perlite and adsorbent treated with polymethyl hydrogen siloxane showed high water repellent properties with a water contact angle exceeding 140° and provided a suitable base layer for super hydrophobic coatings [16]. Perlite-based lightweight repair plasters developed to improve the energy efficiency of historic and aesthetically valuable buildings were found to be suitable for the repair of historic buildings thanks to their lime and natural hydraulic lime content, while cement-lime plasters were found to be unsuitable for use in cultural heritage buildings due to their low water vapor permeability [17]. On the other hand, hydrophobic modification was found to alter the water transport behavior of cement-based materials and 10% paraffin additive significantly reduced capillary and moisture absorption, improving reinforcement corrosion protection performance by one to two orders of magnitude. These studies reveal that expanded perlite offers significant contributions in terms of water resistance, thermal stability and energy efficiency in building materials [18].

Although there have been several studies in the literature on the development of hydrophobic properties, there are no studies that fully demonstrate the potential of lightweight and natural filler materials such as expanded perlite in this field by gaining hydrophobic properties. Most existing studies focus on hydrophobic coatings, additives and chemical-based solutions, and lack a systematic approach to improving the water resistance and thermal insulation properties of natural materials. Existing methods are often costly and have environmental impacts, which necessitates the development of more economical and environmentally friendly alternatives. In particular, it is of great importance to investigate innovative methods that enhance the performance of natural fillers, considering environmental sustainability and cost-effectiveness.

Perlite can be used in lightweight composite production, especially for thermal insulation. However, the fact that it absorbs a lot of water and vomits water after mixing causes problems during production. Giving hydrophobic properties to perlite causes a decrease in water absorption, resulting in more effective products. Studies on the use of hydrophobic perlite in cement and/or gypsum-based composites are very limited. This study aims to enhance the water repellent properties of expanded perlite by making it hydrophobic and to comprehensively evaluate the performance of the combination of this material with cement and gypsum mortars. Firstly, the water repellent properties of this material were optimised using various chemical methods to obtain hydrophobic perlite. The physical and mechanical properties of mortars produced with the obtained hydrophobic perlite, such as water absorption rates, ultrasound transmission rate, unit weight and compressive strength, were evaluated by extensive tests. According to the test results, superior results were obtained especially in water absorption capacities. The results obtained are important for cemented or plastered productions in building parts

where water repellent properties are desired. In this context, the study aims to provide innovative, environmentally friendly and economical solutions to develop both water repellent and energy efficient building materials. With this approach, it is aimed to break new ground in the construction industry for the production of materials with both increased durability and energy efficiency.

## II. EXPERIMENTAL STUDY

### A. Materials

Binder: Votorantim brand (Eskişehir, Turkey) and CEM I 42.5 R gray cement conforming to TS EN 197-1: 2012 standard were used in the experimental studies. Kartek brand (Ankara, Turkey) gypsum conforming to TS EN 13279-1 standard was used as gypsum. The mechanical, physical and chemical properties of the binders are shown in Table 1.

Table 1. Properties of binders

Cement	Chemical content, %				Density, kg/dm <sup>3</sup>	Fineness, cm <sup>2</sup> /g
	CaO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>		
CEM I 42,5 R	63.56	19.25	5.05	2.56	3.1	50-60
Gypsum Plaster	Type	Water/gypsum rates	Initial setting time	pH	Unit weight, kg/dm <sup>3</sup>	Compressive strength, MPa
	C1	7/10	>8min	6-7	1.1	10

Hydrophobic Chemical: Silres BS 3003 brand chemical was used as hydrophobic material. This substance is a solventless emulsion based on a mixture of silane and siloxane, which can be water-thinnable. Diluted solutions of Silres BS 3003 serve as high quality, general-purpose water repellents for impregnating and priming mineral surfaces. Silres BS 3003 is also suitable for the post-hydrophobation of fiber cement products, such as fiber cement boards. The properties of the chemical used in the production of hydrophobic perlite are given in Table 2.

Table 2. Properties of hydrophobic chemical

Silres BS 3003	Appearance	Active substance content, %	Density, kg/dm <sup>3</sup>	Viscosity, mPa.s	pH
	White	60	0.95	12	8

Perlite: Perlite obtained from Uzay Perlit Company (İstanbul, Turkey) was used in the study. The chemical and physical properties of the fibers used in the blend are given in Table 3.

Table 3. Properties of perlite

Perlite	Unit weight, kg/m <sup>3</sup>	Average Grain Size, mm	Chemical Content, %					PH
			SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	MgO	
	50-60	0-3	74	14	3	5	0.5	7

### B. Method and tests

In the experimental study, firstly, the hydrophobization of expanded perlite was studied. Perlite was made hydrophobic by mixing perlite and hydrophobic chemicals with the effect of aluminum balls in the mill. Fig. 1 shows the mill and aluminum balls used in the mixing process. As a result of the trials carried out for the mixing process, it was determined that the optimum mill operating conditions were 600 rpm for 2 minutes.



Figure 1. Balls and mill used in hydrophobic perlite production

After the production of the hydrophobic perlite, the production of the mortar was started. 4 different types of mortar were produced. Cement mortar with pure perlite without hydrophobic properties (PPC), cement mortar with perlite with hydrophobic properties (HPC), gypsum plaster with pure perlite without hydrophobic properties (PPP), gypsum plaster with perlite with hydrophobic properties (HPP). Although the perlite/cement ratio was assumed to be 1, several specimens were produced with water/cement ratios of 1/1.3/1.6. Once the specimens had been produced, tests such as unit weight, ultrasonic pulse velocity, water absorption by weight, capillary water absorption and compressive strength were carried out on the specimens.

### III. FINDINGS AND DISCUSSIONS

Fig. 2 shows the unit weights of the cement and gypsum binder specimens. The unit weight values varied between 1.31 and 0.96 kg/dm<sup>3</sup>. It was observed that the unit weight values of the cement bonded specimens were 5% higher than those of the gypsum bonded specimens. This is because the density of cement is higher than that of gypsum. Due to the additive added to make the perlite hydrophobic, the unit weight values did not show a significant change due to the small amount of additive. As the water/binder ratio increased, the unit weight values decreased by up to 20%. The low density of the water caused the unit weight of the specimens to decrease. These results indicate that the higher density of cement compared to gypsum is the primary factor influencing the unit weight differences between the specimens. Additionally, the significant decrease in unit weight with increasing water/binder ratio suggests that porosity plays a crucial role in determining the overall density of the material.

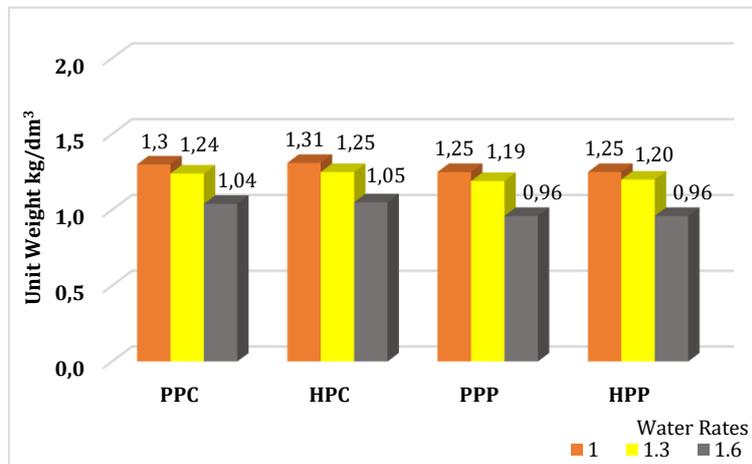


Figure 2. Unit weights of specimens

Fig. 3 shows the wt% water absorption values of cement and gypsum binder specimens containing hydrophobic and normal perlite. The wt% water absorption values varied between 1.78-9.35%. Due to the high water absorption capacity of perlite, the water absorption values of the specimens approached 10%. These values, which are quite high, will prevent sustainability in terms of physical and durability in building elements. However, when hydrophobic properties were added to the perlite, which is the main objective of this study, the water absorption values of the cement-bonded specimens produced decreased to one third by weight. On the other hand, the hydrophobic perlite reduced the water absorption of the gypsum bonded specimens by half. With increasing water content in the production, the water absorption of the samples increased up to 40%. The voids created by the evaporation of the excess water in the samples increased the water absorption rate. As the water absorption capacity of gypsum is higher than that of cement, the water absorption values of the gypsum binder specimens increased up to 30% by weight. These findings highlight the crucial role of hydrophobic perlite in significantly reducing water absorption, particularly in cement-bonded specimens, which is essential for enhancing the durability of building materials. Additionally, the increased water absorption with higher water content during production underscores the importance of optimizing the water/binder ratio to minimize porosity and improve long-term performance.

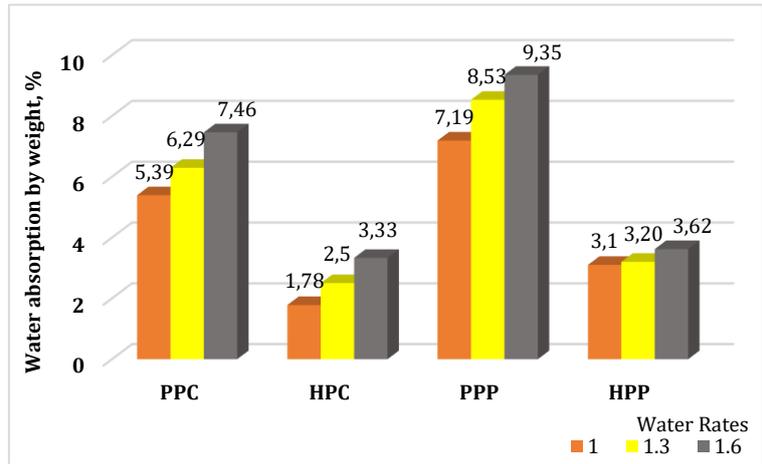


Figure 3. Water absorption by weight of specimens

Fig. 4 shows the capillary water absorption values of the specimens containing perlite and hydrophobic perlite. At the end of 2 hours, the capillary water absorption values of the gypsum specimens were up to 4 times higher than those of the cementitious specimens. The hollow structure of the gypsum, together with the hollow structure of the perlite, caused the formation of capillary water paths. As the increase in the amount of mixing water increased the number of voids associated with the hardened state, the water absorption rates of the specimens increased up to 2 times. In the case of hydrophobic perlite, the capillary water absorption rates decreased by up to one third due to the fact that the water in the capillary spaces changes direction and the connected capillary spaces are blocked due to the fact that perlite does not like water. These results emphasize that the combination of gypsum’s porous structure and perlite’s high void content significantly enhances capillary water absorption, making gypsum-based materials more susceptible to moisture-related deterioration. However, the effectiveness of hydrophobic perlite in reducing capillary water uptake highlights its potential in improving the durability and moisture resistance of lightweight construction materials.

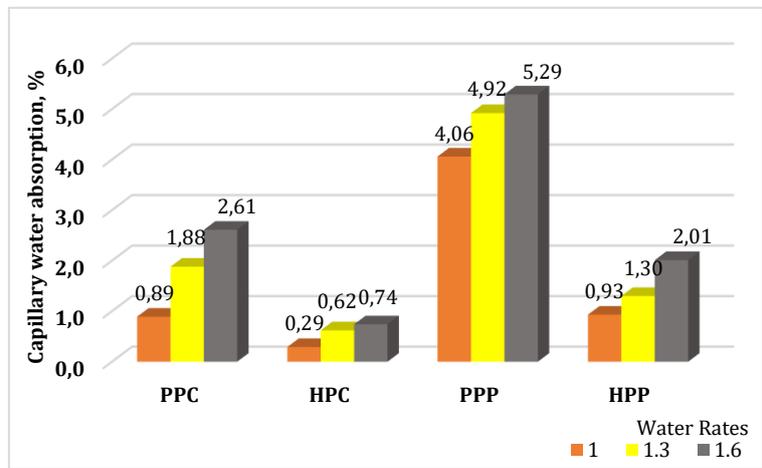


Figure 4. Capillary water absorption of specimens

Fig. 5 shows the values of the ultrasonic pulse velocity of cement and gypsum binder specimens. Analysis of the figure shows that the ultrasonic pulse velocities vary between 1.47-2.04 km/sec. When the cement and gypsum binder samples are examined, it can be seen that the ultrasonic pulse velocity decreases due to the use of hydrophobic perlite. This is due to the fact that hydrophobic perlite increases the number of voids in the mortar structure. At the same time, a decrease in the ultrasonic pulse velocity rate of up to 12% was observed due to the increase in water content in all sample types. As the increase in water content reduced the unit weight values, this also affected the ultrasonic pulse velocity rates. Similarly, as the unit weight values of the gypsum binder samples were lower than those of the cement binder samples, it was found that the ultrasonic pulse velocity values were also lower than those of the cement binder mortars. These findings suggest that the increased void content caused by hydrophobic perlite negatively impacts ultrasonic pulse velocity, which may indicate a reduction in material compactness and strength. However, despite this decrease, the improved water resistance provided by hydrophobic

perlite could enhance the long-term durability of the material, balancing the trade-off between mechanical properties and moisture protection.

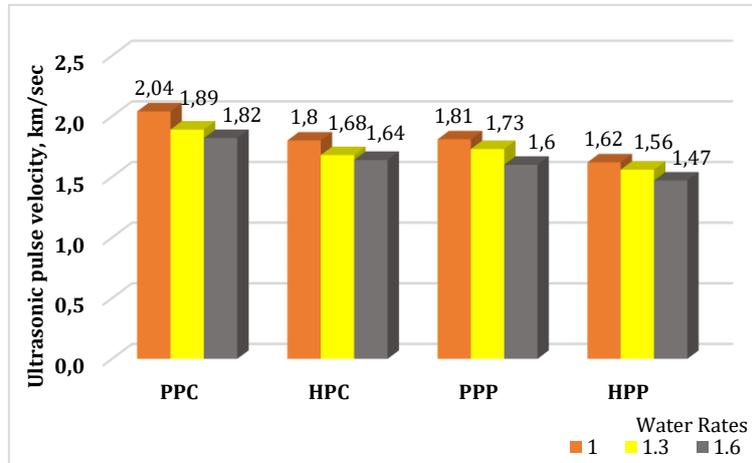


Figure 5. Ultrasonic pulse velocity of specimens

Fig. 6 shows the compressive strength values of the specimens. The compressive strength values varied between 11-20 MPa. It was observed that the compressive strength of the cement bonded specimens was up to 15% higher than that of the gypsum bonded specimens. The fact that cement binds perlite better than gypsum, and contains silicate structures that provide strength, caused the increase in compressive strength. As the water content of the mix increased, the compressive strength of the samples decreased by up to 30%. The void structure formed in the hardened structure by the excess water in the mix was effective in reducing the compressive strength. The compressive strength of the specimens containing hydrophobic perlite decreased by 6% compared to the specimens containing normal perlite. The partial decrease in adhesion due to insufficient water retention at the perlite-cement and perlite-gypsum interfaces as a result of water repulsion by the hydrophobic perlite caused the decrease in strength. These results indicate that while hydrophobic perlite improves moisture resistance, it slightly compromises compressive strength due to reduced adhesion at the binder-perlite interface. However, considering the trade-off between strength and durability, optimizing the mix design and binder composition could help mitigate strength loss while maintaining the benefits of hydrophobic modification.

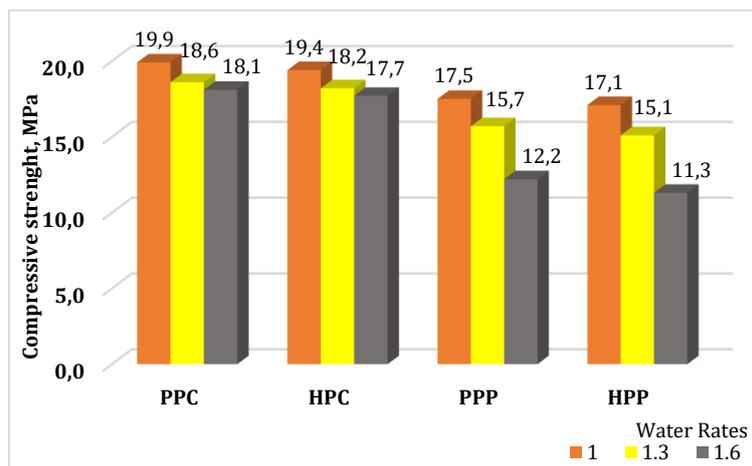


Figure 6. Compressive strength of specimens

#### IV. CONCLUSIONS

The conclusions of the study are summarized as follows:

- While the use of hydrophobic perlite did not cause any significant changes in the unit weight values of the samples, it did cause a decrease in the ultrasonic pulse velocity values due to the increase in the number of voids.

- With the use of perlite, the water absorption rate of the specimens by weight approached 10%, whereas with the use of hydrophobic perlite, the water absorption values by weight decreased by up to 60%. Again, the capillary water absorption rates decreased by up to 70% with the use of hydrophobic perlite. This shows that the use of hydrophobic perlite has a very good effect on the water repellency of mortar specimens.

- It was observed that the use of hydrophobic perlite had little effect on the compressive strength of the specimens. With the use of hydrophobic perlite, the highest decrease in compressive strength of 6% was observed.

The use of hydrophobic perlite extends material life by reducing water absorption and reduces resource consumption by reducing the need for maintenance. It also contributes to the production of lighter and more insulating composites, increasing energy efficiency and promoting the use of sustainable materials in the construction industry. This study investigated the effects of hydrophobic perlite on the water repellency and mechanical properties of different types of mortar specimens. With the experimental results obtained, the use of hydrophobic perlite is recommended for special surfaces where the presence of water in the structure and on the surface is undesirable.

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