



Research Article

Effect of dosage on the mechanical properties of epscrete

Mehmet Canbaz^{a,*} , Emir Günaltılı^a , Uğur Albayrak^a 

^a Department of Civil Engineering, Eskişehir Osmangazi University, 26480 Eskişehir, Türkiye

ABSTRACT

Epscrete, which is made by employing aggregate made of expanded polystyrene beads, is often used to make wall panels, block components, and insulating plates. For these products to have greater mechanical qualities, 400, 600, and 800 dose epscrete specimens were made in this research, which also considered the influence of cement quantity. The water-cement ratio was considered to be 0.5. In addition to the reference specimens, the same manufacture was carried out utilizing a 1% plasticizer admixture. Specimens were subjected to unit weight, ultrasonic pulse, water absorption, bending, and comprehension tests 7 and 28 days after production. The effects of the dose and plasticizer rate on the physical and mechanical properties of early and ultimate epscrete specimens were determined according to the unit weight, ultrasonic pulse velocity, water absorption rates, bending and compressive strength values. Increasing the dosage increased the ultrasonic pulse velocity, reduced water absorption by reducing the amount of gap and reduced water absorption, and increased compressive strength by approximately 65 % and bending strength by about 60 %. It has been determined that the mechanical and physical properties of epscrete are affected by dose and mixture ratios. By increasing the dosage, it has been seen that carrier light carrier blocks can be obtained.

ARTICLE INFO

Article history:

Received 15 December 2022

Revised 29 January 2023

Accepted 8 May 2023

Keywords:

Epscrete

Dosage

Physical properties

Mechanical properties

Lightweight block

1. Introduction

Expanded polystyrene (EPS) blocks can be used for thermal insulation and lightening the structure against seismic effects as Rauf et al. (2011), Mohammed and Zain (2016) and Miled et al. (2004) stated in their studies. However, as Uygunoğlu et al. (2015), the flammability of these materials limits their use. According to Li et al. (2018) and Babu et al. (2006), granules forming EPS blocks are polymers with closed cell structure, high air content, hydrophobic structure, and low density. For this reason, EPS granules can be used in the production of lightweight concrete as noted by Tang et al. (2008). Concrete in which EPS beads are used as aggregate is called EPS concrete. As a result of the cement paste covering the EPS granules, the material becomes incombustible. In this state, it can be used in many areas such as thermal insulation material, floating marine structures, geogrid, and road barrier as used by Gyawali (2023). However, the freeze-thaw resistance of EPS concrete is low. For

this reason, in order to increase the freeze-thaw resistance, antifreeze and silane bonding agent can be applied to the outside of the EPS concrete, as well as EPS can be modified by wrapping the EPS surface with high performance materials, and polyvinyl alcohol and fiber can be added to the mixture by Yuan et al. (2022). Since EPS-based lightweight concrete panels reduce energy consumption by up to 40%, they can reduce carbon emissions by up to 20% as Meddage et al. (2022) stated in their studies. At the same time, it reduces the use of cement and reduces carbon emissions from cement production. According to Prasittisopin et al. (2022) and Xiang et al. (2022), since EPS particle content increases the porosity, it reduces the strengths by up to 45%, while increasing the dynamic performance and improving the fatigue properties. When the stress-strain curves of EPS concrete obtained under axial compression load are examined, firstly, a linear elongation and small cracks form on the surface, while in the collapsed stage, the increase in stress concentration at the interface of EPS beads and

* Corresponding author. Tel.: +90-222-239-3750 ; Fax: +90-222-239-3613 ; E-mail address: mcanbaz@ogu.edu.tr (M. Canbaz)
ISSN: 2149-8024 / DOI: <https://doi.org/10.20528/cjsmec.2023.03.001>

cement leads to the formation of new cracks due to the low strength of the beads. Feng et al.'s (2022) study revealed that concrete loses its bearing capacity during the stress softening phase. When the drying shrinkage of EPS aggregate concrete is examined by Maghfouri et al. (2022), it was observed that EPS cannot resist shrinkage due to its low rigidity increases drying shrinkage. According to Assaad et al. (2022), If waste EPS insulation materials are used instead of aggregate in the production of lightweight reinforced concrete beams, their shear strength decreased by up to 20%. There are studies prepared by Mahmoud et al. (2023) where EPS bead wastes are used for insulation purposes in the production of geopolymer concrete. It has been determined by Vinod et al. (2022) that EPS beads have higher compressive strength than clay bricks and lower than traditional porous blocks when used in foam concrete block produc-

tion. If EPS is wrapped in airgel, its compressive strength can increase up to 137% as Jiang et al. (2022) stated in their papers. In studies like Rosca and Serbanoiu (2022), using EPS by volume instead of aggregate, the compressive strength increased as the aggregate particle size decreased, as well as the EPS bead distribution became more uniform. In a study by Sadrumontazi et al. (2012), in which EPS granules were used as aggregate, the strength increased with the use of silica fume, while the strength decreased with the use of rice husk ash. It has been observed that homogeneity and slenderness are important in studies where fracture is modeled in concretes using CT scanning to obtain the micromorphology of concretes with EPS aggregates. According to Feng et al. (2022), these data provide improvement regarding the design, construction and cure of EPS concrete.

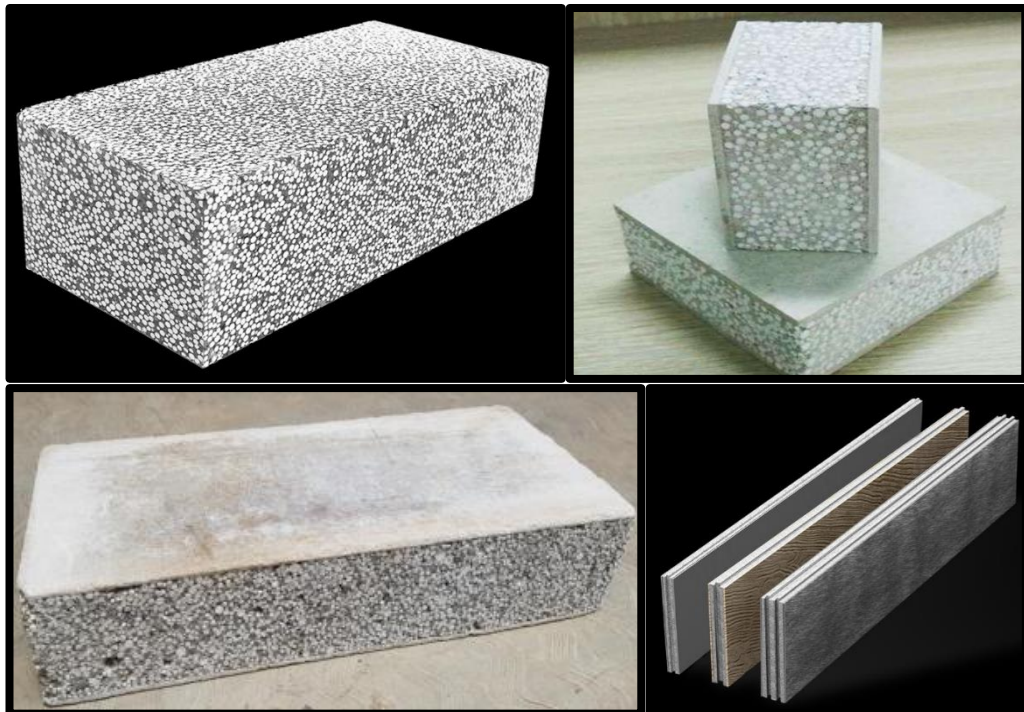


Fig. 1. Epscrete types used in the application (Susilorini et al. 2020; Mishra and Dashore 2020).

As can be seen from Fig. 1, there are a variety of EPS products available, including wall panels, block elements, and insulation plates. There have been previous studies on the strength and durability of epscrete products. In this study, unlike previous studies, a higher amount of cement was added in different proportions and aimed to have higher mechanical properties as well as lighter ones. For this purpose, 400, 600, and 800 dosage epscrete specimens were produced using EPS beads. Here, 400 doses can be used in light concrete applications in general. Therefore, 400 doses were chosen as a reference. If the dosage is increased too much, the upper limit is limited to 800, as there may be too many problems due to the heat of hydration as well as the cost. 600 doses were taken as an intermediate value. Unit weight, ultrasonic pulse, bending, and compressive strength tests were performed on these specimens and

their mechanical and physical properties were determined.

2. Experimental study

2.1. Materials

Cement: Type R CEM I 42.5 cement was used in the mixtures. The properties of this cement are given in Table 1. **Aggregate:** EPS beads were used as an aggregate in mixtures. The properties of the beads were listed in Table 2. **Water:** Municipal water was used in the mixtures. Properties of the mix-water is given in Table 3.

Admixture: The superplasticizer (SP) was mixed as an admixture in a lightweight concrete design. Admixture properties were given in Table 4.

Table 1. Properties of cement.

Chemical content, mg/dm ³									
CaO	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	MgO	Cl-	Na ₂ O	K ₂ O	LOI	SO ₃
62.9	4.56	19.19	3.09	1.88	0.013	0.31	0.63	3.8	3.21
Physical properties									
Specific surface cm ² /g		Expansion, mm		Initial setting, min.		Final setting, min.		Density, g/cm ³	
3590		1		163		227.5		3.09	

Table 2. Properties of EPS beads.

Diameter range, mm	Unit Weight, kg/m ³	Density, kg/m ³
1.5-3.0	20	60

Table 3. Properties of water.

Cu	Mn	Al	NH ₄	Fe	NO ₃	K	Ni	As	Conductivity, μS/cm	pH	Hardness, Fd ⁰
0.016	0.015	0.04	0.06	0.007	11.1	6.8	5.07	1.19	628	7.35	30.11

Table 4. Properties of plasticizer.

Content	Structure	Colour	Density	pH	Cl-	Alkali
Modified lignosulfonate	homogeneous, liquid	dark brown	1.135 kg/dm ³	8	<0.1%	<7 %

2.2. Method and tests

In lightweight concrete containing EPS beads (epscrete) production, the water-cement ratio was taken into account as 0.5. Specimens were taken from the epscrete mixtures prepared according to the mixing ratios given in Table 5 into prismatic molds with dimensions of 4x4x16 cm. The specimens taken from the mold one day later were kept under standard curing conditions until the day of the experiments. Unit weight, ultrasonic pulse, water absorption, splitting tensile, compression and bending tests were carried out on specimens 7 and 28 days after production are showed in Fig. 2.

Table 5. Mixture ratio, kg/m³.

Cement	Water	EPS beads	Admixture (SP)
400	200	20	0
400	200	20	4
600	300	20	0
600	300	20	6
800	400	20	0
800	400	20	8

3. Discussion

The unit weight changes of the epscrete specimens are given in Fig. 3. According to Fig. 3, the unit weights ranged between 0.6 and 1.4 kg/dm³. A decrease in the dosage from 800 kg to 600 kg reduced the unit weights of the specimens by 24%, while a decrease of 400 kg in

the dosage caused the unit weights of the specimens to decrease by 51%. The heaviest component in the epscrete composition is cement. Due to the fact that the other components are quite light compared to cement, the change in the amount of cement caused a significant change in the unit weight of the specimens. Since better placement was achieved by adding a plasticizer to the mixture, an increase in the unit weights of the specimens was observed, reaching 5.7%. It was determined that the unit weights of the specimens were higher due to the low water loss in the early ages, and these values decreased by 8% in 28 days. When the studies of Kuhail (2001), Jayanth and Sowmya (2018) are examined, the unit weights of the epscrete samples using 400 doses of cement are reduced to 0.95 kg/dm³, similar to this study, while the unit weights can reach up to 1.27 kg/dm³ in the case of using 600 doses of cement (Kuhail 2001; Jayanth 2018).

The ultrasonic pulse velocity values of epscrete specimens varies with dosage were shown in Fig. 4. The determination of ultrasonic pulse velocity can provide information about the quality of the concrete by changing the speed as a result of the change in path required for vibration progression depending on the void structure and amount of space in the sample. However, in this study, the presence of EPS beads as well as voids and cement paste in the inner structure was effective in the propagation of the vibration created by the piezoelectric material. Vibration does not propagate in pores, but circulates around it. Hardened cement paste and EPS grains are different types of materials. Cement paste is a ceramic material while EPS is a polymer material. However, since it is an expanded polymer. It contains gaps in

its internal structure and thus can slow down the progression of vibration, therefore, reducing ultrasonic pulse velocity values. In Fig. 4, it was observed that as the dosage increased, the ultrasonic pulse velocity values increased by 78%. Since the admixture provides better

placement, it has reduced the voids and increased the ultrasonic pulse velocity values by up to 20%. The increase in solid structures as a result of the continuation of hydration over time caused an increase in ultrasonic pulse velocity values of up to 14%.

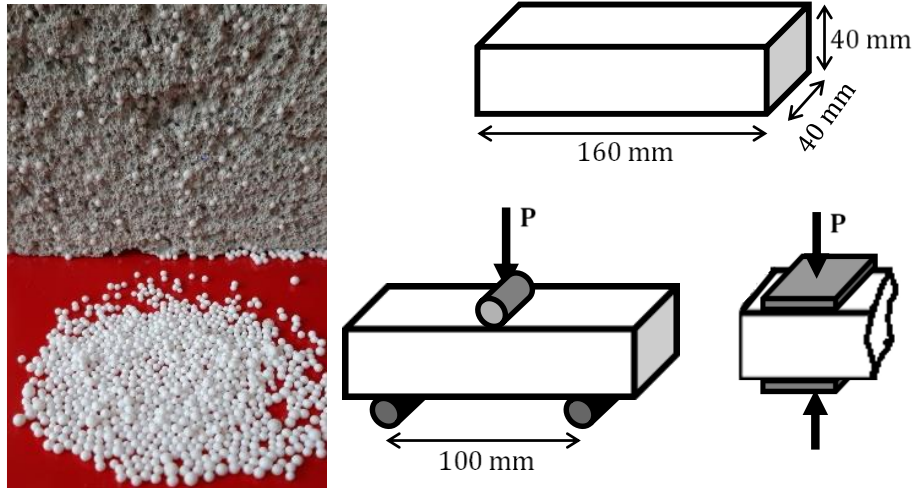


Fig. 2. Mixture, EPS beads, schematic draw of specimens and tests.

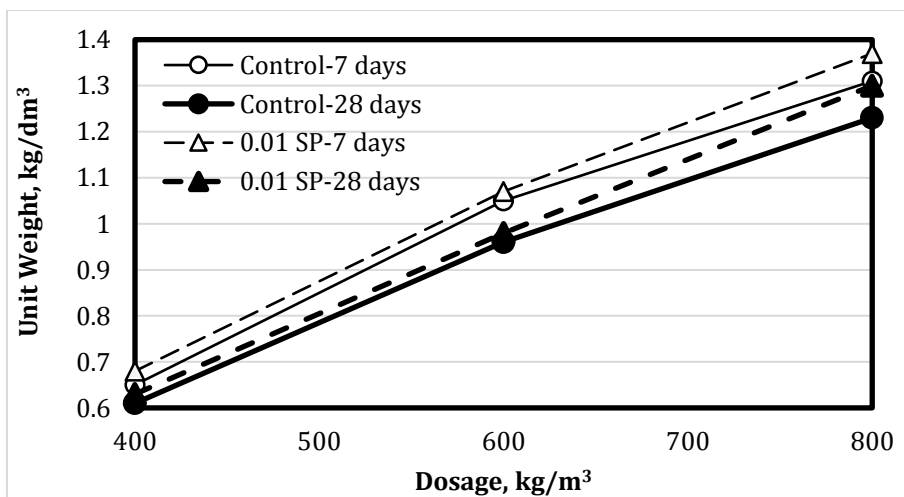


Fig. 3. The effect of dosage on unit weights of epscrete.

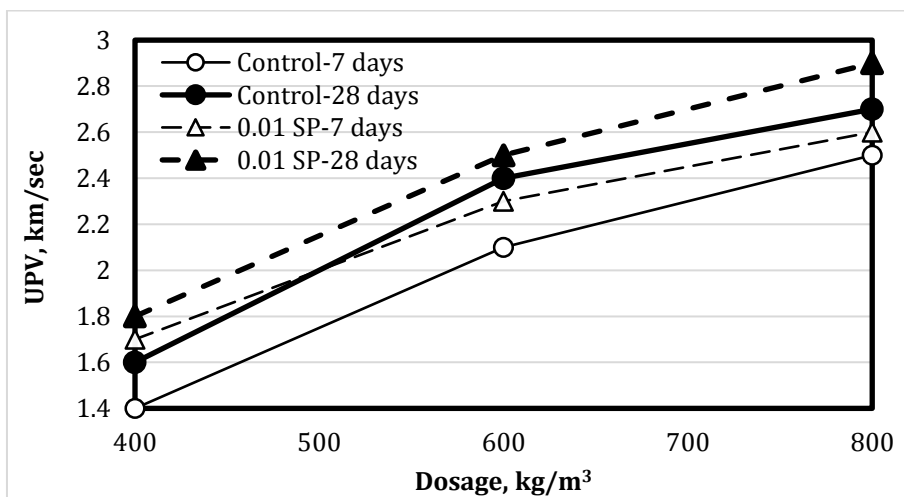


Fig. 4. Ultrasonic pulse velocity change of epscrete with dosage.

The water absorption test results of the produced epscrete specimens 7 and 28 after the production are shown in Fig. 5. It was seen that the water absorption rates by weight ranged between 3 and 14 percent. The capillary voids, micro and macro voids in the cement paste were effective in absorbing water due to the water absorption and impermeability of the EPS grains. Therefore, the water absorption rate of the specimens decreased by 67% as a result of the decrease in voids with the increase in

dosage. The increase in machinability with the addition of admixtures caused a decrease in macro voids and thus a decrease in water absorption rates of up to 12%. In addition, the increase in the microstructure of the GSH structures formed as a result of cement hydration over time caused a decrease in water absorption rates of up to 36%. In previous studies as Jayanth and Sowmya (2018), unlike this study, UPV values were found to be higher, such as 2.64 km/sec, since sand was used.

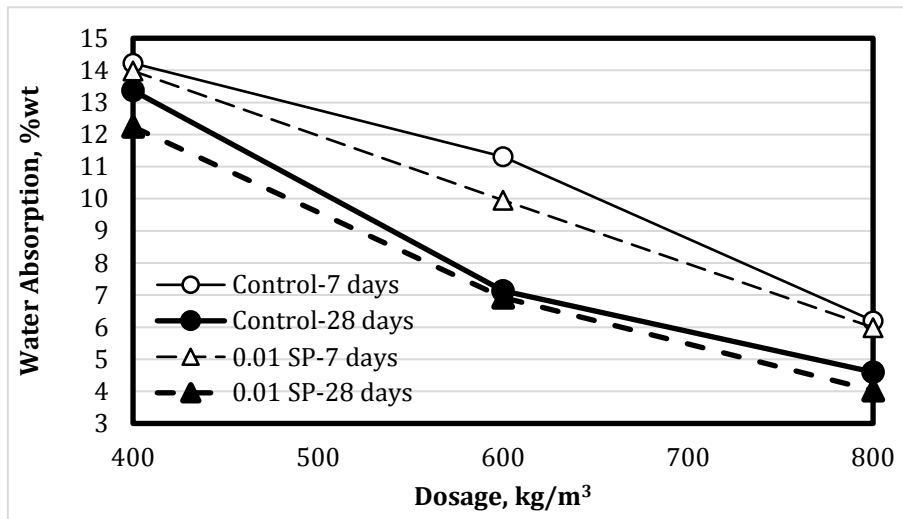


Fig. 5. Water absorption of epscrete.

The bending strength changes determined as a result of the bending test performed on epscrete specimens are shown in Fig. 6. When Fig. 6 was examined, the decrease in dosage in the production of epscrete caused a decrease in the bending strength of the specimens, reaching 40%. The increase in dosage, the better filling of the pores between the EPS granules and the increase in stiffness and strength of the calcium silicate hydrate gels formed as a result of hydration caused an increase in the bending strength. As a result of the dispersion of the cement particle size, the spread of the hydration reactions over time causes the specimens to show continuity even

if the strength gains rate decreases. In this study, it was observed that the bending strength of the 7 day specimens could reach up to 93% of the bending strength of the 28 day specimens. In the case of the addition of plasticizer, the homogeneous distribution that occurs as a result of preventing the flocculation of the cement grains provided better placement in the cross-section, and in this case, the bending strength of the specimens increased by up to 24%. In the studies conducted by Jayanth and Sowmya (2018), it was determined that the flexural strength of epscrete specimens decreased to 0.98 MPa.

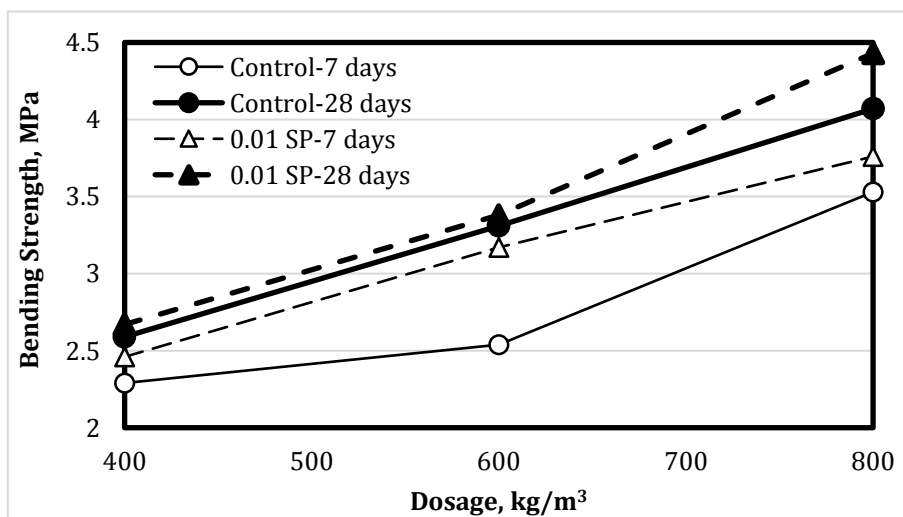


Fig. 6. Effect of dosage on bending strength of epscrete.

The variation in compressive strength of epscrete specimens depending on admixture content, specimen age, and cement amount is shown in Fig. 7. It was observed that the compressive strengths of the specimens varied between 8.5 and 19 MPa. The compressive strengths increased up to 82%, depending on the amount of cement used. In case of an increase in dosage, an increase in strength is an expected situation. However, the use of EPS grains as aggregate in epscrete specimens and the fact that these grains act as voids and do not contribute to strength, it has been observed that the contribution of cement paste to strength is effective. In normal concrete, the 7 day concrete compressive strength is 70% of the 28 day concrete compressive strength. The 7 day compressive strength of Epscrete specimens was at

least 76% of their 28 day compressive strength. The plasticizer admixture separated the cement particles from each other by physical force, preventing segregation and increasing the compressive strength. This increase reached 20% in epscrete specimens. When the studies conducted by Kuhail (2001), Jayanth and Sowmya (2018) are examined, the compressive strength of epscrete samples using 400 doses of cement decreases to 4.5 MPa, while the compressive strength can reach up to 6 MPa in case of using 600 doses of cement.

SEM images of epscrete produced by using EPS beads as aggregate are given in Fig. 8. When Fig. 8 is examined, porous structure of the EPS beads and the microstructure of the interface formed by the bonding of EPS to the cement paste are seen.

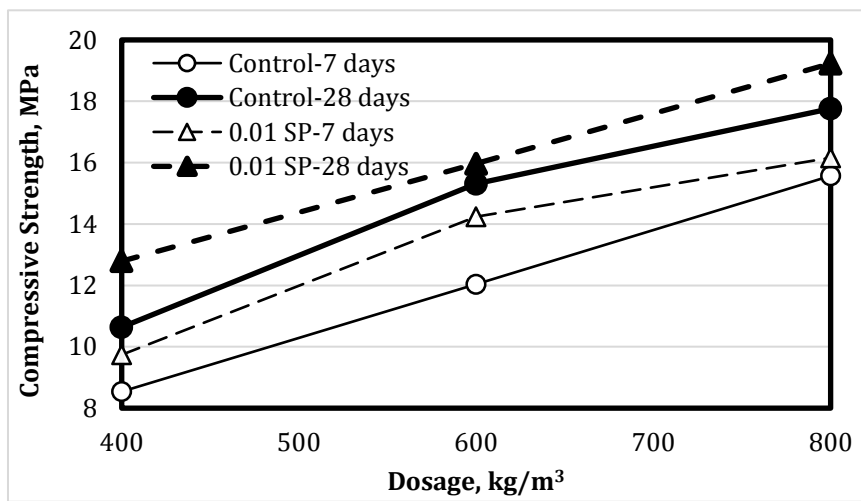


Fig. 7. Compressive strength variation of epscrete with dosage.

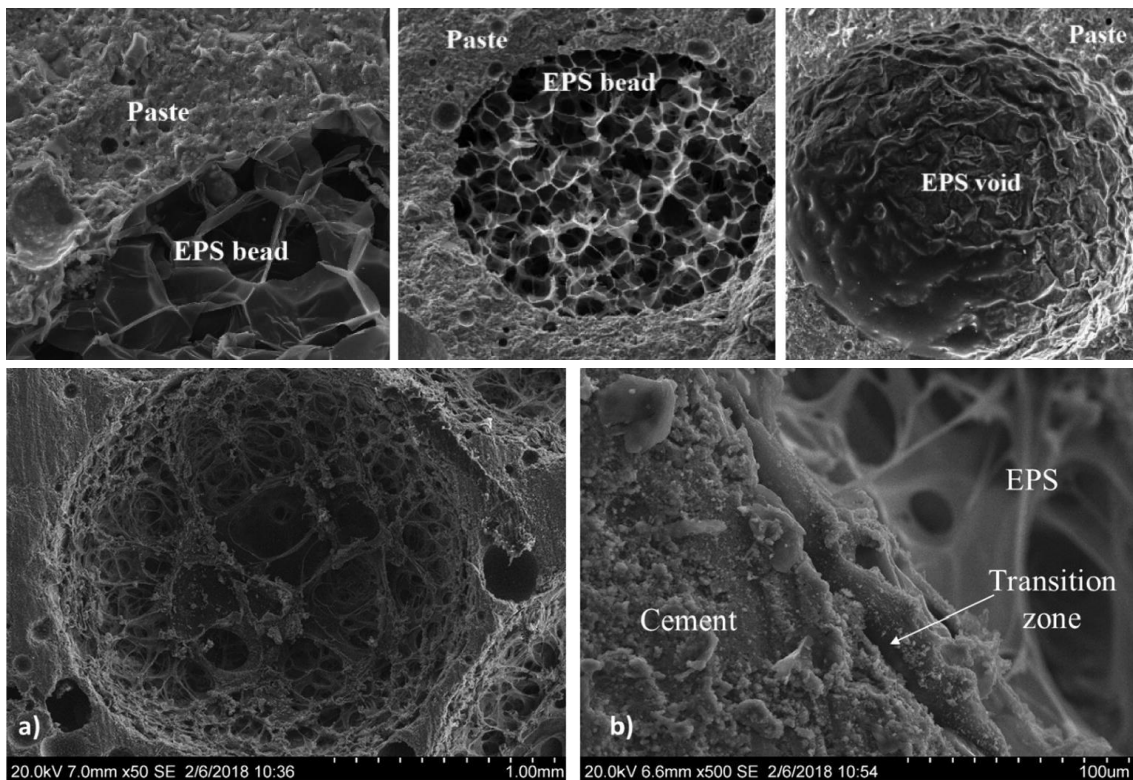


Fig. 8. SEM images of the cement paste/EPS interface and EPS beads (Allahverdi et al. 2018; Maaroufi et al. 2018).

4. Conclusions

The following conclusions were reached as a result of the tests and analysis on epscrete.

- It has been observed that the amount of cement selected such as 400, 600 or 800 kg in epscrete production has a significant effect on the test results to determine the mechanical and physical properties.
- It was observed that the unit weights of 400 dosage epscrete fell below 700 kg/m³. It was determined that the unit weights of the specimens with 800 dosages were over 1200 kg/m³.
- As a result of the decrease in space contained in the specimens and the increase in dosage, the ultrasonic pulse velocity values increased while the water absorption rates decreased.
- Considering the compressive and bending strengths, which are the most important mechanical properties of concrete elements, the dosage increase increased the strengths. While the bending strengths of 400 dosage specimens were 2.6 MPa and the compressive strengths were around 11 MPa, the bending strengths of 800 dosage specimens were around 4.1 MPa and the compressive strengths were around 18 MPa.
- The workability of the mixture has increased with the addition of plasticizer to the epscrete mixture. This situation caused an increase in the unit weight, ultrasonic pulse velocity values, bending and compressive strengths of the specimens and a decrease in the water absorption rate. Especially in 400 dosage epscrete specimens, the compressive strengths reached 13 MPa.
- The physical and mechanical properties of epscrete specimens at 7 and 28 days were determined. While the ultrasonic pulse velocity values and compressive and bending strengths of the 7 day specimens are lower than those of the 28 day specimens, their unit weights are high.
- While 87% of the bending strength was reached in terms of mechanical properties at an early age, 80% of the compressive strength was reached in 400 dosage specimens and 87% in 800 dosage specimens. High strength achieved at an early age was one of the important results of this study.

Epscrete specimens with 800 dosages are suitable to be produced as a partition wall block construction element with their 1.2 kg/dm³ unit weight and 18 MPa compressive strength. The mechanical properties obtained show that these blocks are suitable for use as lightweight load-bearing wall elements in masonry structures. When 400 dosages are preferred in epscrete production, it is recommended to use the products obtained as an insulation plate with unit weights of 0.6 kg/dm³, bending strengths of 2.6 MPa and compressive strengths exceeding 10 MPa. However, in order to be used as an insulation plate, it is recommended to determine the thermal conductivity coefficients in future studies.

Acknowledgements

None declared.

Funding

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

REFERENCES

- Allahverdi A, Azimi A, Alibabaie M (2018). Development of multi-strength grade green lightweight reactive powder concrete using expanded polystyrene beads. *Construction and Building Materials*, 172, 457-467.
- Assaad J, Mikhael C, Hanna R (2022). Recycling of waste expanded polystyrene concrete in lightweight sandwich panels and structural applications. *Cleaner Materials*, 4, 100095.
- Babu DS, Ganesh Babu K, Tiong, Huan W (2006). Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete. *Cement and Concrete Composites*, 28(6), 520-527.
- Feng X, Gong B, Zhao T (2022). Study on the non-linear deformation and failure characteristics of EPS concrete based on CT-scanned structure modelling and cloud computing. *Engineering Fracture Mechanics*, 261, 108214.
- Gyawali R (2023). Effect of the mixing procedure on the properties of lightweight EPS mortar. *Journal of Building Engineering*, 68, 106012.
- Jayanth P, Sowmya M (2018). Experimental Study on replacement of coarse aggregates by EPS beads in concrete to achieve lightweight concrete. *International Research Journal of Engineering and Technology*, 5(7), 610-616.
- Jiang T, Wang Y, Shi S, Yuan N, Ma R, Wu X, Shi D, Sun K, Zhao Y, Li W, Yu J (2022). Compressive behavior of lightweight concrete using aerogel-reinforced expanded polystyrene foams. *Case Studies in Construction Materials*, 17, e01557.
- Kuhail Z (2001). Polystyrene Lightweight Concrete (Polyconcrete). *An-Najah University Journal for Research - A (Natural Sciences)*, 41-61.
- Li C, Miao L, You Q, Hu S, Fang H (2018). Effects of viscosity modifying admixture (VMA) on workability and compressive strength of structural EPS concrete. *Construction and Building Materials*, 175, 342-350.
- Maaroufi M, Abahri K, El Hachem C, Belarbi R (2018). Characterization of EPS lightweight concrete microstructure by X-ray tomography with consideration of thermal variations. *Construction and Building Materials*, 178, 339-348.
- Maghfouri M, Alimohammadi V, Gupta R, Saberian M, Azarsa P, Hashem, M, Asadi I, Roychand R (2022). Drying shrinkage properties of expanded polystyrene (EPS) lightweight aggregate concrete: A review. *Case Studies in Construction Materials*, 16, e00919.
- Mahmoud A, Tawfik A, Abd El-razik M, Faried S (2023). Mechanical and acoustic absorption properties of lightweight fly ash/slag-based geopolymer concrete with various aggregates. *Ceramics International*.
- Meddage P, Chadee A, Jayasinghe R, Rathnayake U (2022). Exploring the applicability of expanded polystyrene (EPS) based concrete panels as roof slab insulation in the tropics. *Case Studies in Construction Materials*, 17, e01361.
- Miled K, Le Roy R, Sab K, Boulay C (2004). Compressive behavior of an idealized EPS lightweight concrete: size effects and failure mode. *Mechanics of Materials*, 36(11), 1031-1046.
- Mishra S, Dashore S. (2020). Analysis of fiber reinforced concrete with EPS. *International Research Journal of Engineering and Technology*, 7(2), 1875-1877.

- Mohammed HJ, Zain M (2016). Experimental application of EPS concrete in the new prototype design of the concrete barrier. *Construction and Building Materials*, 124, 312–342.
- Prasittisopin L, Termkhajornkit P, Ki H (2022). Review of concrete with expanded polystyrene (EPS): Performance and environmental aspects. *Journal of Cleaner Production*, 366, 132919.
- Rauf MA, Shah A, Qazi EH, Tahir M (2011). Evaluation of expanded polystyrene based blocks for lightweight structures in the seismic prone areas. *International Conference on Earthquake Engineering and Seismology* (ICEES 2011), NUST, Islamabad, Pakistan.
- Rosca B, Serbanoiu A (2022). Study on influence of natural aggregate maximum size on compressive strength of polystyrene aggregate concrete of structural grade. *Materials Today: Proceedings*, 61, 433-439.
- Sadromontazi A, Sobhani J, Mirgozar A, Najimi M (2012). Properties of multi-strength grade EPS concrete containing silica fume and rice husk ash. *Construction and Building Materials*, 35, 211–219.
- Susilorini R, Widiyanto D, Ogur I, Prabandaru S (2020). Flexural deformation of expanded polystyrene concrete sandwich beam: An experimental study. *International Journal of Engineering Research and Technology*, 13, 540-7.
- Tang C, Lo Y, Nadeem A (2008). Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete. *Cement and Concrete Composites*, 30(5), 403–409.
- Uygunoğlu T, Güneş İ, Çalış M, Özgüven S (2015). Investigation of behavior of EPS and XPS thermal insulation exterior claddings during fire. *Journal of Polytechnic*, 18(1), 21-28.
- Vinod R, Surendra J, Shobha R (2022). Lightweight concrete blocks produced using expanded polystyrene and foaming agent. *Materials Today: Proceedings*, 52, 1666-1670.
- Xiang J, Song Y, Shu H, Li Z, Qiu J, Gu X (2022). Expanded polystyrene (EPS) particles as a carrier to improve the growth of microorganisms in concrete. *Journal of Cleaner Production*, 369, 133363.
- Yuan J, Li D, Li W, Yang H, Zhang W, Wang L, Wang J, Xiong Z (2022). Study on frost resistance of EPS concrete based on EPS beads wrapping modification. *Construction and Building Materials*, 345, 128400.