



## Research Article

# Effect of expanded polystyrene beads on the properties of foam concrete containing polypropylene fiber

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## ABSTRACT

In this study, foam concrete was produced using 3 different volumes of EPS beads (up to 100%), 3 different volumes of polypropylene (PP) fiber (up to 0.1)%, sand and 40% pre-produced foam which is fixed by volume. The water-cement ratio was 0.4 and the sand-cement ratio was chosen as 1. The foam concrete were cast into molds with a size of 100 x 100 x 500 mm and 150 x 150 x 150 mm prism. Unit weight, ultrasonic pulse, water absorption, splitting tensile strength, bending strength and compressive strength tests were achieved. Foam concrete were kept in laboratory standard conditions. According to the results of study, unit weight and ultrasonic pulse velocity vary between 970-1350 kg/m<sup>3</sup> and 1.6-2.6 km/sec, respectively. The water absorption of the foam concrete decreased up to 65% as the EPS beads ratio increased. Since EPS beads do not contribute to the strength and act like a void, splitting tensile strength in specimens containing EPS beads decreased by up to 70%. The use of fiber contributes to the splitting tensile strength, especially in specimens that do not contain EPS beads, and it increased the strength by 78%. Similarly, the flexural strength of the PP fiber addition increased by up to 70%. As the EPS beads ratio increased, the flexural strengths decreased by 77%. With the addition of PP fiber, the compressive strength increased by 55%. However, since EPS beads' strength is negligible, it caused a 60% decrease in compressive strength.

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## 1. Introduction

Foam concrete is classified as a type of lightweight concrete in which an air gap is created into cement paste or mortar with the help of foaming agent (Ramamurthy et al. 2009). Foam concrete is a building material designed with a unit weight varying between 400 and 1600 kg/m<sup>3</sup>, flowing, self-compacting, and used in non-structural applications with its low compressive strength (Jones and McCarthy 2005; Richard and Ramli 2013; Nambiar and Ramamurthy 2008). The dry unit weight of foam concrete affects many of its physical properties. There are many parameters that affect the dry unit weight, such as the materials used in the mixture, aggregate type, mineral and chemical additives, cement content and type. However, the most important factor affecting all the physical properties of the foam concrete is the

foam volume used in the mixture (Bindiganavile and Hoseini 2008). Foam concrete is known as a material with low cement content and lightweight aggregates with high fluidity and excellent thermal insulation (Ramamurthy and Nambiar 2009). Although foam concrete is not a new material and the first patent date goes back to 1920, it could not find a wide usage area because the foam quality was not as stable as desired. However, after the 2000s, the development of foam production machines with technology has led to an increase in foam stability and production volume of foam concrete. Therefore, foam concrete has made it widely used in applications (Brady et al. 2001).

For semi-structural applications, the fresh, mechanical and transport microstructure properties of foam concrete were investigated by adding polycarboxylate superplasticizers at different water/cement ratios of foam

concrete with a unit weight of  $1500 \text{ kg/m}^3$ . It was concluded that the water/cement ratio and superplasticizer had a significant effect on the properties of foam concrete. With the increase of superplasticizer content, the mechanical and transport properties of foam concrete improved and the optimum results were obtained at a plasticizer content of 1.35. With the use of superplasticizer, it has been observed that a smaller void diameter is formed and better void distribution occurs (Al-Shwaiter et al. 2021). The water absorption, capillarity and compressive strengths of foam concrete produced at different foam volumes and by replacing sand and fly ash with 100% were investigated. The water absorption, capillarity and compressive strength decreased with the increase of the foam volume in the mixture. Fly ash caused an increase in water absorption due to high water-solids requirement (Nambiar and Ramamurthy 2007). In addition, in the other work, it was stated that fly ash plays an important role in the stability and consistency of foam concrete (Nambiar and Ramamurthy 2008). In this study, compressive strengths of foam concretes with unit weights varying between  $1000\text{-}1500 \text{ kg/m}^3$  with the displacement of cement and fly ash up to 75% were investigated. No strength reduction was observed in the replacement of fly ash with cement up to 67%. According to the article, it was determined that the strength increased over time with the increase in the fly ash content (Kearsley and Wainwright 2000). Foam concrete obtained by replacing fly ash with sand, the structural improvement of foam concrete with the addition of silica fume, fly ash, and PP fiber was investigated. The compressive strength of the foam concrete, which has a density between  $1000\text{-}1900 \text{ kg/m}^3$ , including PP fiber and silica fume, varied between 10-70 MPa. In addition, with the addition of PP fiber, the drying shrinkage, creep resistance and tensile strength of foam concrete were greatly increased. Thus, it was concluded that fibered foam concrete can be used in structural applications (Amran et al. 2020). It is aimed to produce foam concrete with an oven-dry density of  $1300 \text{ kg/m}^3$  by replacing up to 30% cement with palm oil fuel ash (POFA). With a 30% POFA displacement, the density was reduced by approximately 43%. This is due to the porous nature of POFA. Displacement of more than 20% POFA caused a decrease in strength (Alnahhal et al. 2021). The fluidity, compressive strength, thermal conductivity and density of foam concretes produced by replacing 75% and 100% of quarry waste with river sand were investigated. The use of quarry sand in high volumes improved the compressive strength, decreased fluidity, and slightly increased thermal conductivity. It has been concluded that foam concrete containing quarry dust will cause less greenhouse gas emissions and less energy consumption (Lim et al. 2017). The hardened properties, void structure and curing method of high porosity foam concrete produced with normal Portland cement were investigated. It was concluded that the porosity, compressive strength and thermal conductivity of the foamed concrete varied between 88.5%-95.4%, 0.12 to 0.75 and 0.036-0.063, respectively (Jiang et al. 2016). The drying shrinkage, compressive strength and splitting tensile strength of foam concrete produced using silica fume, fly

ash and PP fiber was focused on. With the addition of silica fume and PP fibers, the dry unit weight and compressive strength of foam concrete vary between  $800\text{-}1500 \text{ kg/m}^3$  and 10-50 MPa, respectively. Silica fume and polypropylene greatly increase the compressive strength. In addition, PP fiber greatly increases the drying shrinkage and splitting tensile strength of foam concrete (Bing et al. 2012). 3-hour and 28-day compressive strength, thermal conductivity, water resistance and splitting tensile strength of foam concrete produced using magnesium phosphate cement (MPC) were investigated. It has been determined that the 3-hour compressive strength of MPC-based foam concrete is approximately 70% of the 28-day compressive strength. The compressive strength and thermal conductivity of MPC-based foam concrete produced by adding 10% fly ash were found to be 2.4 MPa and  $0.072 \text{ W/mK}$  (Ma and Chen 2017). Thermal conductivity and compressive strength tests of 6 groups of foam concrete varying between 15%, 17% and 20% air content were examined. It was observed that the dry unit weight, compressive strength and thermal conductivity ranged between  $860\text{-}1245 \text{ kg/m}^3$ , compressive strength 2.5-6.5 MPa and thermal conductivity coefficient between 0.021 and 0.035, respectively (Kumar et al. 2018). Foam concrete was produced with a bentonite slurry of 9.1% of its solid content. The compressive strength decreased with the increase of bentonite slurry. It was concluded that foam concrete with bentonite slurry showed better thermal insulation properties (Xie et al. 2018). Workability and strength properties of foam concrete produced by adding up to 20% of waste tire powder were investigated. It was observed that the workability of foam concrete decreased as the volume of tire waste dust increased. The highest compressive strength was obtained in foam concrete produced with 5% waste rubber powder (Mehrabi et al. 2019). As can be seen in Fig. 1, there are partition wall element applications where EPS beads and foam concrete are used together.

A research was conducted on the thermal insulation and bending strength of wall panels with 3 different percentages of EPS particles on the surface area of foam concrete with a fixed density of  $1100 \text{ kg/m}^3$  and a solid/water ratio of 0.25. It has been observed that the flexural strength of the EPS particle decreases at higher volumes and shows lower thermal insulation properties (Priyanka et al. 2021). The compressive strength, fire resistance and thermal conductivity properties of foam concrete containing EPS ranging from 0% to 82.22% by volume were investigated. The density of foam concrete varies between  $150 \text{ kg/m}^3$  and  $1200 \text{ kg/m}^3$ . It was concluded that the fire resistance, thermal conductivity and compressive strength of foam concrete decreased significantly with the increase in EPS volume (Sayadi et al. 2016). It was aimed to investigate a new wall system with foam concrete produced using 50% recycled EPS. It has been concluded that foamed concrete with EPS can compete with precast panel and can be used as the main wall material (Dissanayake et al. 2017).

When the previous studies are examined, there is a lot of research on foam concrete, but there are very few studies evaluating EPS beads in foam concrete. In this

study, apart from using EPS beads in foam concrete, unlike other studies, it was added to PP fiber and its effect on its hardened properties was investigated. High strength is not expected, especially from lightweight concrete. However, these concretes should be made in the form of slabs and should not be shattered while they

are attached with dowels. In general, steel fiber is preferred in case of such mechanical need in concrete. However, for lightweight concrete, it was thought that polypropylene fiber would be sufficient to increase adherence and mechanical performance. For this reason, polypropylene fiber was used.



Fig. 1. EPS beads and foam concrete application (Fernando 2015; Dissanayake et al. 2017).

## 2. Experimental Study

### 2.1. Materials

**Cement:** Type R CEM I 42.5 cement was employed in the experiment. The chemical and physical properties of this cement are listed in Table 1.

**Aggregate:** Fine river sand was used in the foamed concrete mixtures. The sand was taken from Sakarya River in Osmaneli/Bilecik. The granulometry of the sand is provided in Table 2.

**Water:** Eskişehir tap water was employed. The chem-

ical analysis of the drinkable water is provided in Table 3.

**Foam Agent:** The foam agent was mixed with the water 2.5 % by mass and foam solution was produced (80 gr/l). The foam agent which is composed of vinyl resin and calcium naphthalene sulfonate is produced by Aydos Chemicals Company. The properties of the foam agent is listed in Table 3.

**Fiber:** Polypropylene fiber is used as fiber in the production. The properties of this PP fiber is shown in Table 5.

**Expanded polystyrene (EPS) beads:** The Styrofoam aggregate used is granular and expanded polystyrene based material. Unit volume weight is 0.02 kg/dm<sup>3</sup>.

Table 1. Properties of cement.

Chemical properties				Physical properties	
SiO <sub>2</sub>	19.19	K <sub>2</sub> O	0.63	Density, g/cm <sup>3</sup>	3,09
Al <sub>2</sub> O <sub>3</sub>	4.56	Na <sub>2</sub> O	0.31	Specific surface cm <sup>2</sup> /g	3590
Fe <sub>2</sub> O <sub>3</sub>	3.09	SO <sub>3</sub>	3.21	Setting Time(initial), min	163
CaO	62.9	Cl-	0.013	Setting Time(final), min	227.5
MgO	1.88	LOI	3.8	Expansion, mm	1

Table 2. Granulometry of sand.

Sieve size, mm	2	1	0.5	0.25	0.125
Granulometry, %	100	67.8	47.4	16.6	2

**Table 3.** Properties of mixing water.

Chemical property, mg/l						Physical property	
Al	0,04	Cu	0.016	Ni	5,07	Conductivity, $\mu\text{S}/\text{cm}$	628
$\text{NO}_3$	11,1	Fe	0.007	K	6,8	Hardness, $\text{Fd}^0$	30.11
$\text{NH}_4$	0,06	Mn	0.015	As	1,19	pH	7.35

**Table 4.** Properties of foam agent.

pH	Cl, %	Freezing point, $^{\circ}\text{C}$	Color	Density $\text{kg}/\text{dm}^3$	Alkali, %
5.23	<0.1	-5	Brown	1.041	<0.5

**Table 5.** Properties of PP fiber.

Type	Length, mm	Diameter, mm	$L/d$	$\sigma_{\text{tensile}}$ MPa	E, GPa	Density, $\text{kg}/\text{dm}^3$	Melting point, $^{\circ}\text{C}$
High Grade (fibrofor)	20	0.3	67	400	4.9	0.91	150

## 2.2. Method and tests

In foam concrete production, the water-cement ratio was chosen as 0.4, and the sand-cement ratio was chosen as 1. PP fiber was added to the prepared cement mortar mixture first, and then EPS beads were added. It was mixed with the previously prepared foam cement mortar. The mixing ratios are given in Table 6. 15 cm cube specimens were taken from the prepared mixture and subjected to standard curing conditions ( $23 \pm 2$   $^{\circ}\text{C}$ , lime-saturated water).

The specimens taken from the mixture prepared with the ingredients shown in Fig. 2 were removed from the cure tank 28 days after production, and unit weight, ultrasonic pulse, water absorption, tensile splitting, compression and bending tests were performed on the specimens. Each experiment was carried on at least three specimens. Considering the results of the experiments, the unit weights, ultrasonic pulse velocities (UPV), water absorption rates, split tensile strength, compressive strength and flexural strength of the specimens were calculated.

**Table 6.** Mixture ratio.

Water/cement	Sand/cement	EPS beads, %	Fiber, %	Foam, %
0.4	1	0	0.00	40
		50	0.05	
		100	0.10	

**Fig. 2.** Mixture ingredients, specimens and tests on these specimens.

### 3. Discussion

The change of foam concrete unit weights with EPS Beads and PP fiber are present in Fig. 3. When Fig. 3 was examined, foam concrete unit weights with EPS Beads and PP fiber varies between 970-1350 kg/m<sup>3</sup>. It was observed that unit weights decreased by up to 24% by using EPS Beads instead of sand. The low density of EPS beads compared to sand caused a decrease in unit weights. PP fiber addition increased the unit weights below 5% in specimens containing EPS beads, while it increased by 18% in specimens without EPS beads. Since the PP fiber addition negatively affected the foam distribution in foam concrete without EPS beads, it caused an increase in the unit weights.

Fig. 4 shows the effect of EPS beads and PP fiber ratio on UPV of foam concrete specimens. When Fig.4 was examined, foam concrete was seen that the UPV values varied between 1.6-2.6 km/sec. It was observed that the

void system and EPS beads contained in foam concrete reduce UPVs. When the rate of EPS beads is 50%, the UPV values decrease by 30%, while the rate of decrease is 8% when the rate of EPS beads is 100%. The effect of the PP fibers on UPV has particularly pronounced in specimens without EPS beads. Increasing the PP fiber ratio in these specimens increased the UPV values by up to 40%. The biggest factor in this increase is that the vibration passes the gaps in a shorter time thanks to the PP fibers.

The water absorption rates by weight found as a result of the water absorption test performed on the foam concrete specimens are given in Fig. 5. When Fig. 5 was examined, as the EPS beads rate increases, the water absorption rate decreased by 65%. The fact that EPS beads do not absorb water has been effective in reducing this rate. In addition, the addition of PP fiber caused a partial closure of the cracks and capillary spaces that caused the water to enter the foam concrete, resulting in a decrease in the water absorption rate up to 69%.

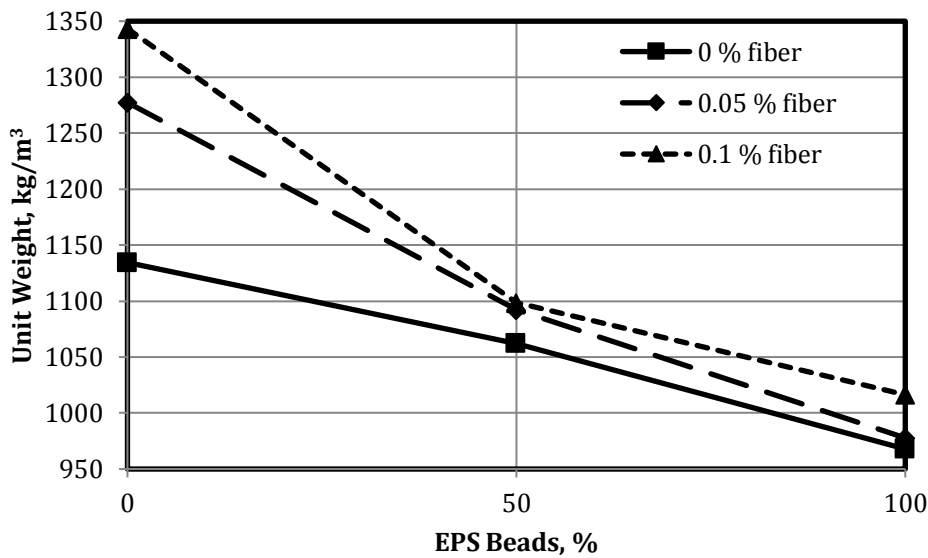


Fig. 3. Unit weight of foam concrete.

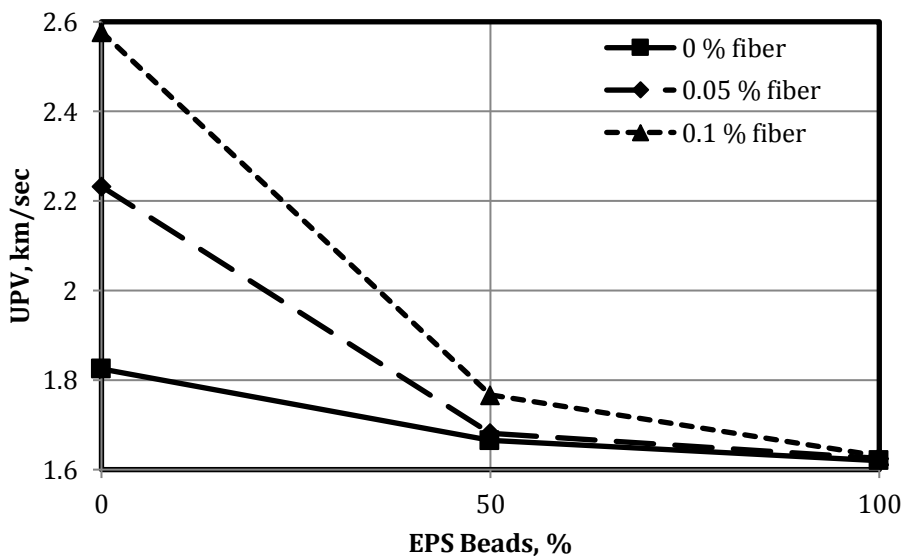


Fig. 4. UPV test results of foam concrete.

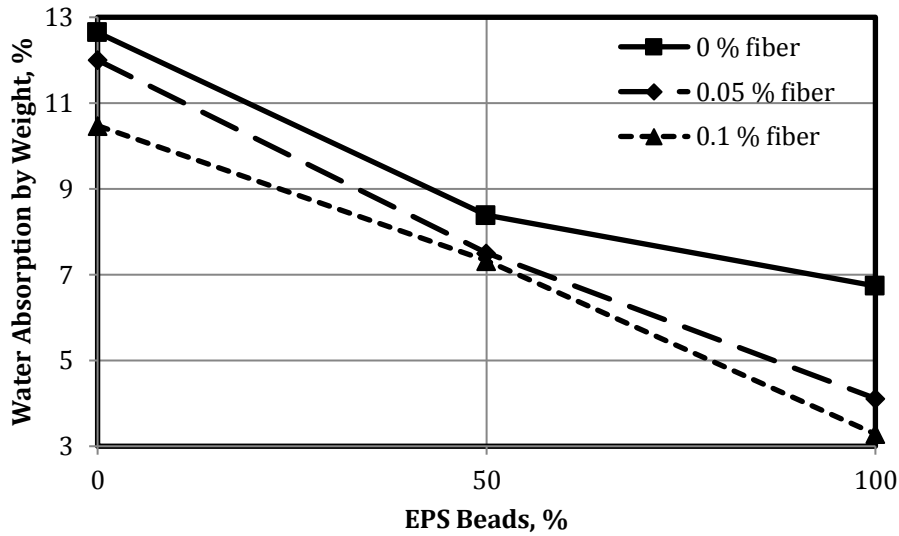


Fig. 5. Change of water absorption rate in foam concrete.

The tensile strength changes of the specimens in splitting depending on the PP fiber and EPS beads ratio are given in Fig. 6. When Fig. 6 was examined, Since EPS beads do not contribute to the strength and act like voids, the splitting tensile strength of the specimens containing EPS beads decreased by up to 70%. The use of PP fiber contributes to the splitting tensile strength, especially in specimens that do not contain EPS beads, and increased the strength by 78%. However; in the specimens containing EPS beads, the positive effect of PP fiber addition on the splitting tensile strength of the specimens decreased to 20%. The PP fibers prevented cracks formed in the specimen under the effect of linear load, spreading brittle suddenly and splitting. In cracks formed under linear load, the PP fibers first began to load with the bridging effect. As a result of the increase in load, its function has ended with the breaking or stripping of the PP fibers. This has resulted in an increase in strength.

Bending test results on foam concrete specimens are present in Fig. 7. When Fig. 7 was examined, the flexural

strength of PP fiber addition increased by 70%, similar to splitting tensile strengths. As the EPS beads ratio increased, the flexural strengths decreased by 77%. Since the mid-point loading method was used as the bending test, the PP fibers in this section prevented the splitting into two due to the cracks formed under the bending effect, since the bending effect was created at a single point, similar to the split tensile test.

The changes in compressive strength depending on the EPS beads and PP fiber contained in the foam concrete specimens are given in Fig. 8. When Figure 8 was examined, the compressive strength increased by 55% with the addition of PP fiber. Since the compressive strength affects the entire volume in an area, the PP fibers provided a more controlled growth of micro cracks formed under the pressure effect as the load increased. Therefore, the fibers were effective in increasing the compressive strength regardless of the EPS beads content. Since EPS beads have an easily deformable structure with negligible strength, they acted like a void under pressure and caused their compressive strength to decrease by 60%.

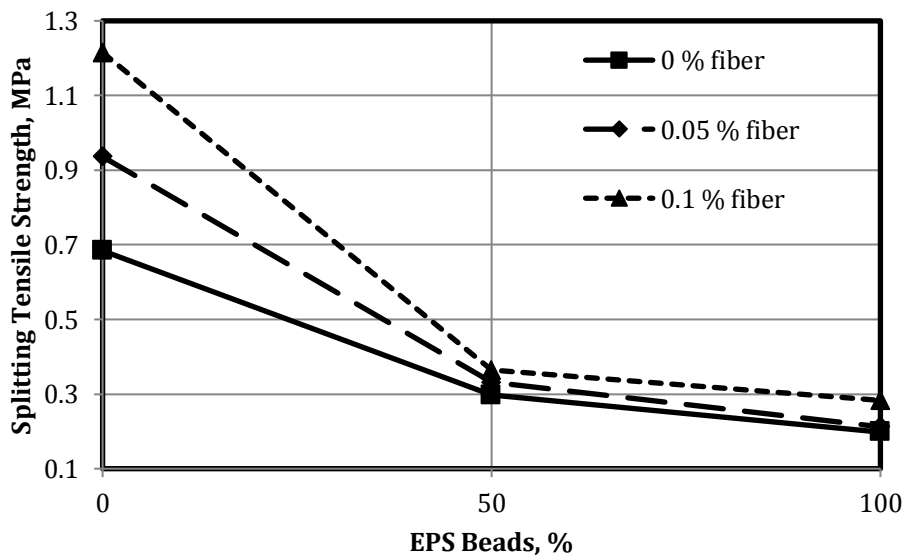


Fig. 6. Splitting tensile strength of foam concrete.

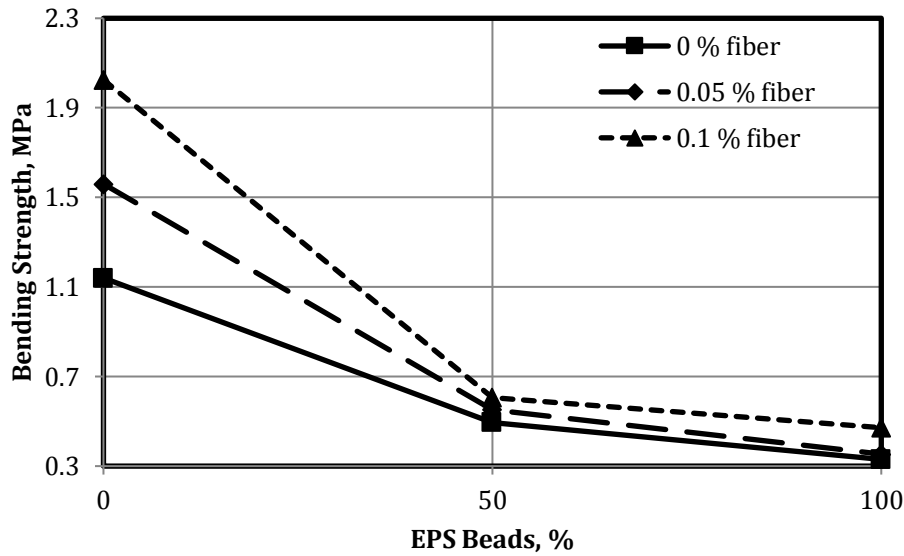


Fig. 7. Bending test results of foam concrete.

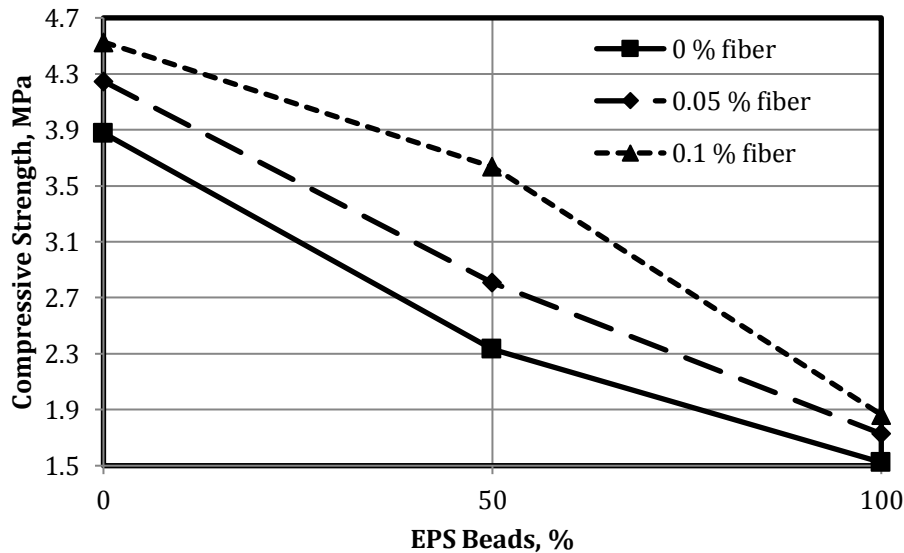


Fig. 8. The change of compressive strength with the ratio of PP fiber and EPS beads in foam concrete.

#### 4. Conclusions

The conclusions of the study are summarized as follows:

- As a result of the substitution of EPS beads instead of aggregate in foam concrete, it observed that the unit weight values decreased below  $1000 \text{ kg/m}^3$ , ultrasonic pulse velocity decreased by 11% to  $1.6 \text{ km/sec}$ , water absorption rate by weight decreased by 47%, and decreased below 7%, splitting tensile strength decreased by 70% to below 200 KPa, the bending strength decreased by 70% to below 400 KPa, and the compressive strength decreased by 60% to below 2 MPa.
- In the case of adding PP fiber to foam concrete, unit weights increase by 18% and reach  $1350 \text{ kg/m}^3$ , ultrasonic pulse velocity increase by 40% and reach  $2.6 \text{ km/sec}$ , water absorption ratios by weight decrease by 17% and decrease to 10%, splitting tensile

strengths It was determined that the flexural strengths increased by 78% and exceeded 1.2 MPa, the flexural strengths increased by 78% and exceeded 2 MPa, and the compressive strengths increased by 17% and exceeded 4.5 MPa.

- In case of adding PP fiber to EPS beads aggregated foam concrete, unit weights increase by 5% and exceed  $1000 \text{ kg/m}^3$ , ultrasonic pulse velocity exceed  $1.63 \text{ km/sec}$  with 1% increase, water absorption rates by weight decrease by 50% and reach 3%. , splitting tensile strengths increased by 43% and exceeded 280 KPa, bending strengths increased by 43% and exceeded 470 KPa, compressive strengths increased by 22% and approached 1.9 MPa.

As a result of the study, the use of 0.1% PP fiber in foam concrete is recommended because it improves the mechanical properties despite increasing the unit weight. By using EPS beads instead of aggregate in foam concrete, unit weights can be reduced below 1000

kg/m<sup>3</sup>. Considering the mechanical properties of EPS beads aggregate foam concrete, it is seen that it can be used as an insulation plate. For this purpose, it is recommended to measure thermal conductivity values in future studies. In order to further reduce the unit weight values, it is recommended to carry out studies to increase the ratio of the foam solution in the mixture. In case of using EPS beads, it is recommended to investigate the behavior of high temperature and fire effects for new studies.

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### Conflict of Interest

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

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