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Research Article

Comparison of mechanical and physical properties of screed with and without expanded polystyrene (EPS) particles

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ABSTRACT

In this study, in order to observe the mechanical and physical properties of ordinary screed, sandy-lightweight screed and lightweight screed samples, expanded polystyrene (EPS) was used as fine aggregate and lightweight screed systems were produced by replacing sand at 100%, 50% and 0%. Samples of cement dosages of 250, 300, 350 kg/m^3 were produced for lightweight screeds, sandy-lightweight screeds and ordinary screeds. Unit weight, water absorption capacity, flexural strength, compressive strength, fire resistance, abrasion and thermal conductivity tests were performed on the produced screed systems. As a result of the research, it was determined that as EPS ratio increases in screed system; unit weights decreased, water absorption rates increased. Besides, the flexural and compressive strengths, fire and abrasion resistance are also decreased. However, it was observed that the thermal conductivity coefficient reduced with the increment of EPS particles in the screed. In normal, sandy-lightweight and lightweight screeds, it was determined that as the cement dosage increased; the unit weights, flexural and compressive strengths, fire and abrasion resistance increased, water absorption capacity and the thermal conductivity coefficient decreased.

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INTRODUCTION

A traditional screed mixture consists of cement, aggregate and water. As heat and sound insulation rules have gotten more strict, it has been suggested that new goods must be developed that can compete in terms of performance with existing products [1]. In general, lightweight aggregates are divided into 2 classes: natural and artificial. Diatomite, pumice and volcanic slag are examples of natural aggregates, while clay, expanded shales, and perlite are examples of artificial aggregates [2]. Lightweight aggregates can affect both fresh and hardened state properties of concrete in different ways, depending on their origin and qualities [3]. Because the aggregate is stronger than the transition zone

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Table 1. Chemical composition of Portland cement (%)

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O+0,658K_2O	Cl^-	Free CaO	LOI
Portland cement	18.80	5.81	2.61	62.90	1.29	2.74	0.74	0.033	0.70	3.27

and matrix, aggregate strength has no effect on concrete strength in normal weight concrete. But, since lightweight aggregate's strength is generally lower than the strength of the other 2 phases, the concrete's strength depends on the lightweight aggregate's strength [4]. Lightweight concrete is usually used to decrease a dead mass of the structure and to decrease the potential of earthquake damage. Because the earthquake forces affecting the structures are directly proportional to the mass of the structures. Therefore, if the weight of the structure is decreased, it is possible to decrease the risks caused by the acceleration of earthquake [5]. It is known that lightweight concrete is approximately 28% lighter than normal concrete [6]. Additionally, low density aggregates result in reduced stress concentrations in concrete and cause less micro cracks in the cement paste matrix compared to normal density aggregates. When compared to conventional concrete, lightweight concrete has a more uniform stress distribution at the micro level, resulting in greater endurance in hard conditions and increased concrete impermeability [6].

Polystyrene beads are a type of aggregate commonly used and easily added to system to obtain lightweight concrete in a variety of densities. Expanded polystyrene(EPS) is a stable low density foam with separate air gaps in the polymer matrix [7]. Small polystyrene beads generated from the styrene via polymerization process make up EPS [8]. It has been stated in previous publications that with altering the volume proportion in mortar or concrete, EPS can be utilized as an ultra-lightweight aggregate appropriate for not only structural but also non-structural purposes [9]. EPS is a material that attracts attention in construction applications thanks to its many advantages [10–13]. These advantages are can be listed; good performance, less material usage and cost of installation, resistance to moisture penetration and biodegradation [10]. Brás et al. [12] noted that the water produced by the EPS beads in EPS bead mortar samples allowed the workability to rise, notably between 5 and 15 minutes, and this had a favorable impact on the workability of the mortar mixes. Besides, it is constructed of pre-expanded polystyrene beads, which have excellent thermal insulation qualities [12]. Its availability in a large variety of densities and sizes is another positive property [10]. Unlike other artificial lightweight materials, EPS aggregates are commercially accessible all around the world [14].

In this study, the properties of normal screed (NS), sandy-lightweight screed (SLS) and EPS granular lightweight screed (LS) samples were examined and compared with each other. Normal screed prepared with sand as fine aggregate, sandy-lightweight screed prepared using 50% less sand and adding 5 grams of EPS particles and lightweight screed samples prepared by adding 10 grams of EPS particles without using any sand were investigated. Normal screed, known as traditional screed, contains sand, cement and water. EPS particles used in lightweight screed production are combined with agents, which are a special additive material, under the factory conditions. Lightweight screed is produced by mixing EPS particles with Portland cement and water in certain proportions in the construction site environment.

For this research, normal screed, sandy-lightweight screed and lightweight screed samples produced with cement dosages of 250, 300, 350 kg/m^3 were adjusted to almost the same workability. The amount of EPS added was calculated by reducing the volume according to the amount of sand. The prepared samples were cured in water at room conditions. Unit volume weight, water absorption and void ratio, flexural strength, compressive strength, abrasion resistance, fire resistance and thermal conductivity properties were examined in screed samples.

MATERIALS AND METHODS

Materials

Portland cement (PC) CEM I 42,5R was used in this study. Chemical composition of PC is given in the Table 1. Specific gravity of cement is 3.15 g/cm^3, and its specific surface area is 3561 cm^2/g. Normal screed samples were prepared by using 0–4 mm natural river sand as fine aggregate. The properties of the fine aggregate obtained as a result of the experiments on fine aggregate are presented in Table 2. The properties of EPS particles used in the research are given in Table 3. EPS materials are combined with a concrete additive material called an agent in order to form a bond between EPS particles and cement mortar in the factory environment.

Mix Proportion

A total of 9 different mixes were prepared with the constant water/binder ratio of 0.6. Normal screed (NS), sandy-lightweight screed (SLS) and lightweight screed (LS) systems were produced. Normal screed, sandy-lightweight screed and lightweight screed specimens are produced at 250, 300, 350 kg/m^3 cement dosages. Mixing ratios for mortar samples are presented in Table 4. The mixtures were casted into molds of 40×40×160 mm^3, 71×71×71 mm^3 and 500×500×50 mm^3 and they were re-

Table 2. Properties of natural river sand

	Specific gravity (SSD) (g/cm³)	Water absorption capacity (%)	Fineness modulus	Amount of filler (%)	Loose unit weight (g/cm³)	Strict unit Weight (g/cm³)
River sand	2.32	4.61	2.39	0.20	1.653	1.784

Table 3. Properties of EPS particles

	Thermal conductivity (W/mK)	Cohesion (kPa)	Modulus of Elasticity	Permeability	Acoustic performance (dB)	Flexural strength (MPa)	Compressive strength (MPa)
EPS	0.067	82.62	–	11.50	14	0.46	0.83

moved from the molds after 24 hours and cured in water at room conditions (21±1 °C) until the test days.

Methods

The 40×40×160 mm³ prismatic specimens were cured in water for 28 days and then removed from the water and dried in an oven, and specimen's weight were measured. The unit weights of the mortars were determined by dividing the weight of the samples by their volume. Water absorption capacity was determined on prismatic samples of 40×40×160 mm³ cured in water for 28 days. The samples, which were kept at 105±5 °C for 24 hours in an oven, were kept at room temperature at the end of 24 hours and their oven dry weights were measured. Then, the samples were kept in water at room temperature (21±1 °C) for 24 hours. After 24 hours, the samples were taken out of the water, the outer surfaces of the samples were dried and their saturated surface dry (SSD) weights were determined. The water absorption capacity (%) can be determined by dividing the difference between the SSD weight of the sample and the oven dry weight of the sample by the dry weight of the sample, multiplying the result by 100. The flexural and compressive strength of 40x40x160 mm³ prismatic screed samples were determined on the 7 and 28 days in accordance with TS EN 1015-11 [15]. The prismatic screed specimens, which were cured in water for 28 days, were removed from the water and dried by furnace at 105±5 °C for 24 h. Then it was exposed to high temperatures of 300 ºC in the oven. The temperature increase rate of the oven was set as 1 °C/min. After the furnace was kept at these 300 ºC for 1 hour, the furnace was turned off and the specimens were left to cool in the furnace in order not to expose the samples to the effect of sudden temperature changes. Flexural strength and compressive strength tests were performed after the screed samples were allowed to cool down to room temperature. To determine the abrasion resistance of the systems, 71×71×71 mm³ cubic screed samples were produced and determined in accordance with TS 2824 EN 1338 [16]. The average of three samples was taken for result of all experiments. The brand of the device for which the thermal conductivity test is performed is "Thermtest", and the model is the "heat flow meter". The thermal conductivity coefficient of the 500×500×50 mm³ sized samples was determined by using the enclosed plate device. Surface temperatures are controlled by foils with thermocouples placed on both surfaces of the samples. Temperature changes were recorded from the cooler and heating plate by means of thermocouples and calibrated cables.

Table 4. Mixing ratios for 1 m³ of samples

Sample name	Cement (g)	Sand (g)	EPS granule (g)	Water (g)
NS 250	250	1883	–	150
NS 300	300	1776	–	180
NS 350	350	1649	–	210
SLS 250	250	942	5	150
SLS 300	300	883	5	180
SLS 350	350	825	5	210
LS 250	250	–	10	150
LS 300	300	–	10	180
LS 350	350	–	10	210

3. RESULTS AND DISCUSSION

Unit Weight, Water Absorption and Thermal Conductivity

The results of measurement of unit weight, water absorption and thermal conductivity coefficient are presented in Table 5. Considering the results shown in Table 5 and Figure 1, unit weights of hardened screed samples were found to be between 0.26 and 2.22 g/cm³. The increase in the amount of cement in the screed samples causes the unit weight values to increase. For example, the unit weights of the SLS 250, SLS 300 and SLS 350 samples are 1.26, 1.30 and 1.4 g/cm³, respectively, and this behavior is similar in the other sample series. However, the use of EPS particles instead of sand aggregate in the mixture causes a decrease in unit weight.

Table 5. Unit weight, water absorption and thermal conductivity coefficient

Sample code	Unit weight g/cm³	Absorption %	Thermal conductivity W/mK
NS 250	2.13	7	0.575
NS 300	2.17	6.7	0.752
NS 350	2.22	5.4	0.784
SLS 250	1.26	11.9	0.296
SLS 300	1.3	10.6	0.344
SLS 350	1.4	9.3	0.392
LS 250	0.26	46.8	0.073
LS 300	0.28	40.8	0.083
LS 350	0.32	39.1	0.091

Table 6. Abrasion results of all specimens

Sample code	Abrasion (mm³/5000 mm²)	Weight loss (%)
NS 250	19570	5.5
NS 300	9987	2.8
NS 350	7008	2.4
SLS 250	24568	6.6
SLS 300	13270	3.7
SLS 350	10938	3.0
LS 250	63324	18.3
LS 300	40786	12.1
LS 350	29805	8.4

The unit weights of NS 250, SLS 250 and LS 250 samples with the same cement values were 2.13, 1.26 and 0.26 g/cm³; the unit weights of the NS 300, SLS 300 and LS 300 samples were 2.17, 1.30 and 0.28; the unit weights of NS 350, SLS 350 and LS 350 samples are 2.22, 1.4 and 0.32 g/cm³, respectively. According to the Table 5, the EPS particles increases the water absorption capacity and the highest water absorption percentages are 46.8%, 40.8% and 39.1% for the LS 250, LS 300 and LS 350 samples, respectively. At the same time, the increase in cement in all screed mixtures reduces the water absorption capacity.

Moreira et. al [1] also showed this inverse ratio between the cement amount in the mixture and the water absorption capacity in the literature. The amount of heat transmitted from the unit thickness and unit temperature gradient in a direction perpendicular to the unit area surface is the thermal conductivity of the material. Porosity is one of the characteristics that has a substantial impact on the sample's thermal conductivity and due to the poor thermal conductivity of air, closed pores decrease the conductivity [17–19].

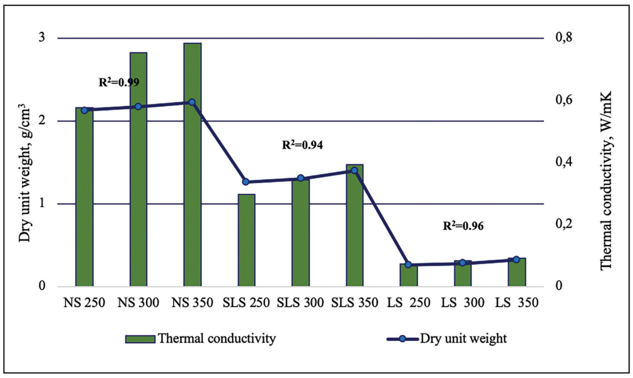


Figure 1. Unit weight and thermal conductivity.

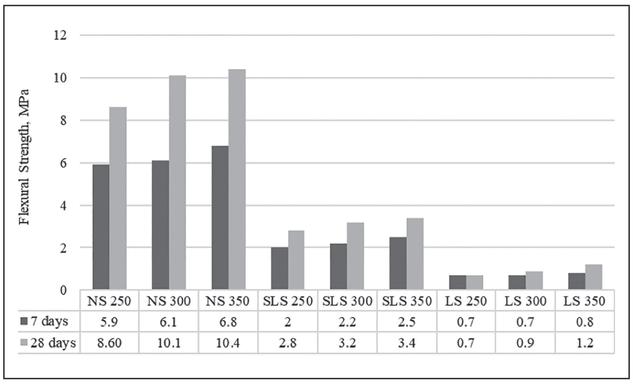
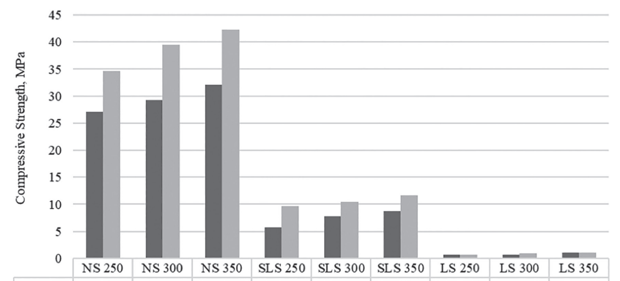


Figure 2. Flexural strengths of the screed mixtures.

The linear relationship between unit weight and thermal conductivity is shown in Figure 1. Replacing the aggregate with the EPS particles increased the total porosity of the samples and decreased the thermal conductivity. This results is in line with the literature [20]. Thus, as seen in Figure 1, there is a linear relationship between the unit weights of the samples and their thermal conductivity, as in many studies [19, 21]. Based on Figure 1, the correlation coefficient of the linear relationship between unit weight and thermal conductivity is 0.99, 0.94, 0.96, respectively. The variations obtained are similar to those reported in previous studies of lightweight concretes [19, 21–23].

According to many studies, the inclusion of lightweight aggregates in cementitious systems results in a decrease in the thermal conductivity of the lightweight composite cementitious system [1, 22–24]. The addition of EPS causes a decrease of 49% for SLS 250 and 75% for LS 250 in the use of 250 kg/m³ cement compared to references in thermal conductivity coefficients. Similar reduction percentages are also encountered in the use of 300 kg/m³ and 350 kg/m³ cement. It is seen that the thermal conductivity of the NS 350, SLS 350, LS 350 samples, each of which contains 350 kg/m³ cement in three different series, is higher than the others, that is, the low cement content reduces the thermal conductivity.



	NS 250	NS 300	NS 350	SLS 250	SLS 300	SLS 350	LS 250	LS 300	LS 350
7 days	27.1	29.3	32.1	5.7	7.8	8.7	0.6	0.7	1
28 days	34.6	39.5	42.3	9.7	10.4	11.7	0.7	0.9	1.1

Figure 3. Compressive strength of the screed mixtures.

Flexural and Compressive Strength Results

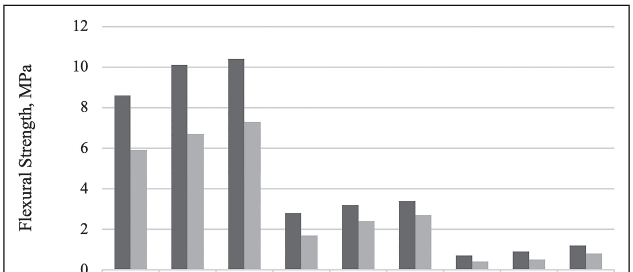
Figure 2 and Figure 3 demonstrated that flexural strength and compressive strength of the screed mixtures prepared with and without EPS was compared at 7 and 28 days, respectively. As shown in Figure 2, 7 day flexural strength values of NS screed mixtures prepared without EPS addition are 5.9, 6.1, 6.8, while the values of SLS screed mixtures are 2.0, 2.2, 2.5, and the values of LS screed samples are 0.7, 0.7, 0.8. Similar behavior is also present at 28-day flexural strength values. On the other hand, in Figure 3, the 7 day compressive strength values of NS screed mixtures prepared without EPS addition are 27.1, 29.3, 32.1, while the values of SLS screed mixtures are 5.7, 7.8, 8.7 and the values of LS samples are 0.6, 0.7, 1.0. Likewise, a similar situation was observed at 28-day values. These strength values show a decrease with EPS added to the mixtures and therefore the lowest strength values belong to LS 250, LS 300 and LS 350. The results of the flexural and compressive strength of the screed samples increased in direct proportion to the cement content. Due to the presence of EPS particles, the flexural cross-section height decreases and the flexural strength decreases [19, 25].

Fire Resistance

The high-temperature (300 °C) heating impact on the compressive and flexural strength of NS, SLS and LS specimens are displayed in Figure 4 and Figure 5. After applying high temperature to the samples, the use of lightweight aggregate in the screed mixtures causes a decrease in the structural strength and it has been observed that the samples containing lightweight aggregate, namely SLS and LS, have a higher fire resistance. The porosity formed during production of EPS results in a lower thermal conductivity and coefficient of thermal expansion, and they show less loss of strength in the fire resistance test.

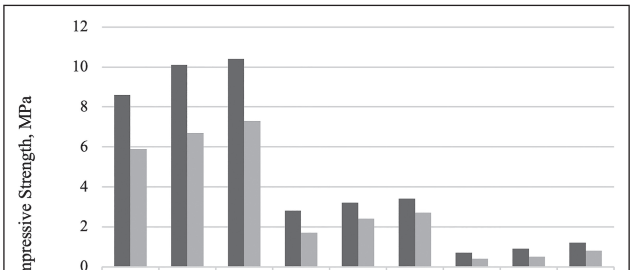
Abrasion Resistance

The measurement results of the screed specimens are presented in Table 6. The results show that the addition of lightweight aggregate to the mixture of screed specimens reduces the abrasion resistance, that is, it has the highest abrasion value and the highest weight loss. The increase in cement content of the screed samples decreased the amount of abrasion and weight loss. In other words, the lowest ones in each series are NS 350, SLS 350 and LS 350. The increase in cement content of the screed samples decreased the amount of abrasion and weight loss. The increment in cement content of the screed samples decreased the amount of abrasion and weight loss, which was observed in three group sample series.



	NS 250	NS 300	NS 350	SLS 250	SLS 300	SLS 350	LS 250	LS 300	LS 350
unheated	8,6	10,1	10,4	2,8	3,2	3,4	0,7	0,9	1,2
heated	5,9	6,7	7,3	1,7	2,4	2,7	0,4	0,5	0,8

Figure 4. Comparison between heated and non-heated flexural strength of specimens.



	NS 250	NS 300	NS 350	SLS 250	SLS 300	SLS 350	LS 250	LS 300	LS 350
unheated	8,6	10,1	10,4	2,8	3,2	3,4	0,7	0,9	1,2
heated	5,9	6,7	7,3	1,7	2,4	2,7	0,4	0,5	0,8

Figure 5. Comparison between heated and non-heated compressive strength of specimens.

CONCLUSIONS

Based on the experimental results of the use of EPS in the screed mixtures formed in this study, the following conclusions can be drawn:

1. It has been observed that the unit weight of the NS samples is higher than the LS containing EPS particles and the SLS samples, and this is due to the porous structure of the replaced EPS particles instead of the aggregate. Increasing the EPS volume in the mix reduces the unit weight of the sample due to the higher air content. Due to this porous structure, water absorption increases and since the pores prevent heat

conduction, it reduces thermal conductivity. That is, unit weight and thermal conductivity behave in direct proportion to each other. The increase in the amount of cement in the mixture limited the porous structure. The unit weight of the LS samples of the porous structure formed due to the addition of EPS particles to the mixtures are smaller than SLS and NS samples. With the effect of the pores in this structure, the thermal conductivity properties are likewise NS, SLS and LS, from largest to smallest, respectively.

2. The expected strength loss has occurred due to the material structure of the EPS particles and the amount of air entering the mixture with the addition. Therefore, NS samples were found to have higher flexural and compressive strengths than SLS and LS samples containing EPS particles. Among the two, LS samples have the lowest strength values since they contain the most EPS. In addition, the increase in the amount of binder material in the mixture within the sample groups increased the strength values slightly.
3. The porosity that occurs in the use of EPS particles relative to their fire resistance values results in a lower thermal conductivity and thermal expansion coefficient, and they show less strength loss in fire resistance testing. NS samples without EPS particles showed greater differences when exposed to 300 °C. The increase the increase in the amount of binder provided a slight increase in the fire resistance values.
4. It has been observed that EPS particles reduce the abrasion resistance of the samples due to the material structure and the porosity caused in the samples. NS samples are more resistant to abrasion than LS and SLS samples containing EPS particles. The reason for this is that the aggregate is more resistant to abrasion than EPS particles. It was clearly seen that the increase in binder in the mixture increased the abrasion resistance in all samples.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

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

ETHICS

There are no ethical issues with the publication of this manuscript.

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