The Effect of Adding Expanded Polystyrene Beads (EPS) on Polymer-Modified Mortar

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Received: 26 July 2022 | Revised: 10 August 2022 | Accepted: 11 August 2022

Abstract-This study assessed the efficiency of Expanded Polystyrene (EPS) waste as a 10, 20, 30, 40, 50, and 60% substitute for fine aggregate in the manufacturing of lightweight cement composites. A 4% low-cost latex paint emulsion was added to the cement mortar to reinforce it as an alternative to the more expensive polymer admixtures. This improved the bonding between the cement matrix and the EPS particles because SBR films were produced in the cement matrix. The flexural strength of regular EPS concrete may also be significantly increased by SBR treatment. Eight alternative mix designs were created and evaluated for compressive and flexural strength, thermal conductivity, water absorption, and dry density. The polymer-modified mortar was created using a 0.4 water/cement ratio of local cement, polymer, and polystyrene. The results showed that compared to the standard combination at 28 days of aging, the compressive strength increased up to 29.26Mpa, flexural strength increased to 6.83Mpa, dry density increased up to 1930kg/m³, and absorption decreased by 4.95. Thermal conductivity decreased by 0.8291W/m.k.

Keywords-Polymer Modified Mortar (PMM); polymer; polystyrene; compressive strength

I. INTRODUCTION

Chemically or steam-processed polystyrene foam components are heated at high temperatures to produce Expanded Polystyrene (EPS), a Lightweight Artificial Aggregate (LWA). Round, closed-cell polystyrene particles have a density between 20 and 35kg/m³ and are composed of 98% air [1, 2]. Sandwich panels, floor decks, and curtain walls with increased thermal and acoustic insulation often use these lightweight nonstructural components. [2]. Environmentally friendly and inexpensive sound materials are becoming more popular. EPS is often used in packaging with minimum absorption and low cost because of its low density, hydrophobic characteristics, and excellent thermal insulation. Globally, an estimated amount of 14 million metric tons of polystyrene are manufactured each year and a large portion of the produced waste is placed in landfills [3, 4]. Styrene Butadiene Rubber (SBR) latexes may reduce bleeding and segregation in the cementitious matrix [5]. The network and the filler are two distinct parts of a polymeric composite. The dispersed stage and fortification are other names for this stage. The disseminated media is responsible for further structural progress. The goal is to better connect the matrix to the filling [6] Polymer-Modified Mortar (PMM). With the right mix of cement and latex, PMM is an ideal product for use in the construction industry. Concrete and mortar characteristics may be altered by polymers. This material has higher tensile strength, improved chemical resistance, long-term use, and less environmental impact [7]. Latex improves the adhesive or bonding strength of materials such as pastes, mortars, concretes, tiles, bricks, steel, wood, and stone compared to the industry's unaltered counterparts [8]. Instead of cement, SBR is used in civil engineering to improve the hardened properties of concrete [9]. Adding SBR to strong concrete alters its physical properties. SBR is the most often used cement mortar modifier. The resulting cement hydrate and polymer layer have excellent adhesion properties. This results in less deformation and a more excellent crushing and flexural strength than conventional concrete [10]. SBR latex is widely used in a variety of modified solutions to enhance impermeability and frost resistance.

SBR latex has often been used to repair reinforced concrete structures. Several studies found that adding SBR latex to cement mortar increased bonding and flexural and tensile strength. This study attempts to improve the bonding between EPS particles and cement paste by including SBR latex in EPS concrete mixtures, improving compressive strength, flexural strength, thermal conductivity, and water absorption.

II. MATERIAL CHARACTERIZATION

A. Cement

This study used OPC Cement I 42.5N. Tables I and II show its chemical and physical characteristics, which are in accordance with Iraq's specification No. 5/2019 [11].

B. Fine Aggregates

The used fine aggregates met the criteria in [12], had excellent gradation, were free of dangerous chemicals that might affect the examination's findings, went through the 0.6mm sieve, and passed the sieving test.

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C. Water

According to [13], the utilized water was pure and devoid of contaminants.

D. Polymer

The SBR polymer was utilized without any treatment to make the Polymer Cement Mortar (PCM) mixes. Table III lists the SBR polymer's physical characteristics.

E. Expanded Polystyrene Beads

This study used spherical EPS beads with a maximum nominal size of 5mm instead of fine aggregates in certain instances. Table IV shows the physical characteristics of the EPS beads and the particle size gradient discovered during the EPS sieve analysis. Figure 1 shows the prepared EPS beads in a spherical shape.

TABLE I. CEMENT'S CHEMICAL COMPONENTS

Oxide composition	Result	Limits of [12]
CaO	62	-
SiO_2	20.1	-
Al_2O_3	4.24	-
Fe_2O_3	4.16	-
SO_3	2.15	≤ 2.8% if C3A>3.5 ≤ 2.5% if C3A<3.5
MgO	3.65	≤ 5%
Loss on ignition	3.42	≤ 4%
Insoluble residue	0.71	≤ 1.5%
Cement compounds [24]		
C_3S	59.02	
C_2S	29.65	
C_3A	4.21	
C_4AF	12.65	

TABLE II. PHYSICAL PROPERTIES OF CEMENT

Physical properties	Test result	Limits of [12]
Specific surface area, Blaine method, (m²/kg).	295	≥ 250 m^2/kg
Setting time -Initial setting (min) -Final setting (min)	 1:38 3:45	 ≥ 45 min ≤ 600 min
Compressive strength of mortar (MPa) 2-days 28-days	 20.4 27.5	 ≥ 10 N/m^2 ≥ 42.5 N/m^2
Soundness % (autoclave)	0.35	≤ 0.8

TABLE III. PHYSICAL PROPERTIES OF SBR POLYMER

Specifications given by the company	
Appearance	Milky white
Specific Gravity	1.02 ± 0.2 @ 250°C
Chloride content	Nil (EN 934-2)
PH value	7 - 10.5

TABLE IV. CHEMICAL AND PHYSICAL PROPERTIES OF EPS

Sieve size	Passing%	ASTM C 330
4.75mm	6.5	5–40
2.36mm	1.5	0–20
Physical properties		
SO_3%	–	
Specific gravity	–	
Absorption	0	
Maximum particle size	5	

Fig. 1. Expanded polystyrene beads.

III. EXPERIMENTAL WORK

A. Mixing

An electric mechanical mixer with a capacity of 0.1m^3 was used. Cement and fine aggregates were first added to the mixer and stirred for 1min. Following the proper dilution with water, the SBR polymer dispersion was added and mixed for around 3min at low speed. Finally, the other EPS particles were blended with the initial materials for an additional two minutes. Due to their low density, compared to other ingredients in the combination, this was done to guarantee that the polystyrene granules would not volatilize. The remaining water was added to the components that had already been mixed slowly and steadily for another 3 to 5min to get a homogeneous mixture free of segregation. Table V displays the percentages of the materials utilized in this production.

TABLE V. DETAILS OF MIXTURE PROPORTIONS

Mix	C:S	W/C%	Polymer:cement%	EPS%	Flow (mm)
E1	1:3	0.58	0%	0%	85
E2	1:3	0.4	4%	0%	100
E3	1:3	0.4	4%	10%	145
E4	1:3	0.4	4%	20%	147
E5	1:3	0.4	4%	30%	150
E6	1:3	0.4	4%	40%	155
E7	1:3	0.4	4%	50%	165
E8	1:3	0.4	4%	60%	190

B. Casting, Compaction, and Curing

Metal sheets were placed on top of the molds to prevent the samples from evaporating while remaining in the molds for 24h. This is the most effective way to cure polymer-containing concrete [14]. After being soaked in water for 72h, the samples were removed from the molds and left to dry until evaluation. The total number of samples prepared in this study was 168.

IV. RESULTS AND DISCUSSION

A. Flow Test

Figures 2 and 3 illustrate how an increase in replacement% helped boost the flow for EPS samples [15], validating that the hydrophobic properties of EPS aggregates were the higher value of the cause of the flow test. The natural aggregates exhibited angular shapes, while EPS particles were spherical. Therefore, more EPS causes more lubrication between the particles, which reduces friction and increases the flow test [16].

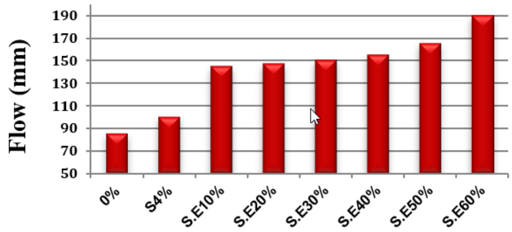

Fig. 2. Flow and effect relationship of EPS and SBR addition.

Fig. 3. Flow test.

B. Compressive Strength

This test was conducted using cubic specimens 50×50×50mm in size [17]. The test ages were 3, 7, and 28 days, and 3 cubes were examined for each age. The SBR concrete without EPS had the maximum compressive strength (up to 42.6MPa), surpassing the benchmark mix. In terms of combinations, the percentages of EPS by weight of fine aggregates were 10, 20, 30, 40, 50, and 60%. Adding more polystyrene, the inadequate film formation caused a considerable reduction in the compressive strength of the polymer EPS concretes. The greatest compressive strength value was found for the 10% polystyrene replacement ratio (up to 29.26MPa), as shown in Figures 4 and 5. Compressive strength dropped as the percentage of polystyrene increased [18].

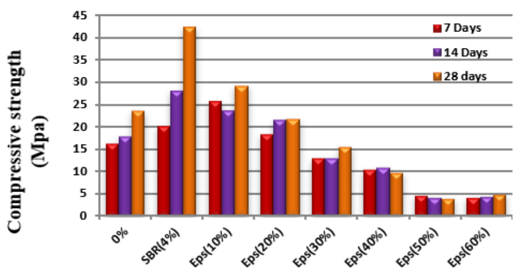

Fig. 4. Relationship of compressive strength and EPS.

Fig. 5. Testing cubic concrete sample.

C. Flexural Strength

Flexural strength determines how materials react to simple beam loads [19]. This test employed dimensional prismatic specimens (40×40×160mm) with various curing ages (7, 14, and 28 days). Three prisms were examined for each age. Figures 6 and 7 show the results. Figure 6 shows that the sample with a 10% substitution with EPS had flexural strength values that were greater than the standard, and even greater than the values of the SBR 4% mixing container. As the EPS ratio decreased, the flexural strength increased. An increase in flexural strength was accompanied by a rise in density because polymeric coatings increased the flexural strength of cured concrete [20].

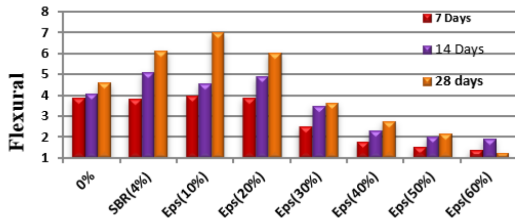

Fig. 6. Relationship between flexural strength and EPS.

Fig. 7. Testing a prismatic concrete sample.

D. Thermal Conductivity

Cylinders measuring 100×200mm were produced to measure thermal conductivity [21]. The test was carried out at 28 days of age on 3 samples for each age. Thermal conductivity and density were shown to be closely related. Figures 8 and 9 show that thermal conductivity decreased when density declined. Porosity increased with EPS levels, which resulted in a reduction in heat conductivity. Adding SBR to the combinations had a considerable negative impact on thermal conductivity. The findings demonstrate that the density and volume of EPS impacted the thermal conductivity of the concrete. The partial replacement of fine aggregate with EPS was responsible for the change brought about in the lower density and greater air spaces of EPS beads, which resulted in the reduction of thermal conductivity outcomes of mixtures [22].

E. Water Absorption

The beads were hydrophobic because they were made of polystyrene sulfonate EPS. Figure 10 shows that the results of the absorption test worsened as EPS content increased. With increased EPS particles, mortars become more porous internally, making it easier for water to enter the mortar [23].

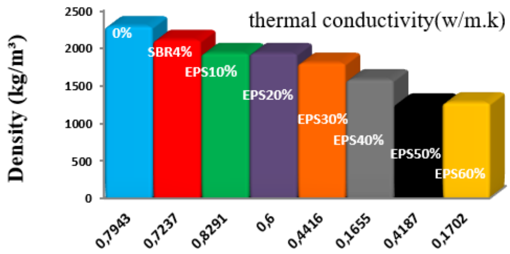

Fig. 8. Relationship between thermal conductivity and density.

Fig. 9. Testing a cylinder concrete sample.

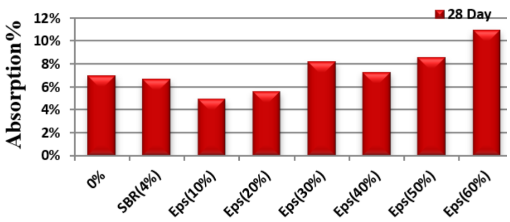

Fig. 10. Relationship between absorption (%) and EPS.

V. CONCLUSION

The evaluation of thermal conductivity, flexural strength, and compressive strength of polymer-modified mortar and expanded polystyrene beads led to the following conclusions:

- At 28 days, the reference mixture's compressive strength at 10% replacement increased by 5.46%. Systematic reductions were made when the use of EPS use increased.
- At 28 days, the 10% replacement attained the greatest flexural strength of 6.83MPa.
- SBR enhanced overall porosity, decreased density, and created artificial micropores. Because of this, the partial substitution of aggregate with EPS may be blamed for the lower thermal conductivity. The material's insulating quality also increased due to the samples' decreased thermal conductivity.
- EPS demonstrated a successful use as a substitute material in the construction of nonstructural elements. It also provided a solution to the disposal of expanded polystyrene waste. Concrete's density and compressive strength decreased as the proportion of EPS substitute increased. The 10% EPS was best suited for non-structural uses, such as wall building and ornamental moldings. However, since it tends to break quickly under strain, 30, 40, 50, and 60% replacement should not be utilized for non-structural reasons. Therefore, it is advised to include polystyrene in concrete mixtures when low-density (lightweight) concrete is desired and resistance is unnecessary.
- At 28 days, the 10% EPS replacement combination's water absorption was 4.95% lower than the reference mixture.

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