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Influence of Waste Polystyrene Foam on the Engineering Properties of Concrete Made from Local Materials

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Abstract: One of the waste materials currently used in the manufacture of lightweight concrete is polystyrene. However, the effects of this material on most concrete properties have not been studied in Libya. In this paper, experimental data for plain concrete were obtained by replacing natural sand with waste polystyrene foam (WPSF) in volume ratios of 0%, 10%, 20%, and 30%. The properties of concrete, such as slump, air content, density, water absorption, compressive strength, flexural strength, free shrinkage, and UPV, were determined experimentally. The findings indicate that as the amount of WPSF in the concrete mix increases, the slump, density, compressive strength, and flexural strength as well as the elastic modulus and UPV of the plain concrete decrease. Conversely, an increase in the replacement level of natural sand by WPSF leads to an increase in air content, water absorption, and free shrinkage. Even though the incorporation of WPSF did not enhance most of the established engineering properties of concrete, the results obtained still fall within the acceptable limits for concrete use in all engineering applications. As such, this type of concrete may be suitable for construction applications that require less thermal and acoustic insulation.

Keywords: Plain concrete, Engineering properties, Waste polystyrene foam, Natural sand

1. Introduction

One of the biggest consumers of raw materials nowadays is the building industry. There must be a significant decrease in the consumption of raw resources if we are to have a sustainable future. For this reason, it is crucial to consider waste reduction and material recycling both during the construction of new structures and during the recycling of demolition materials [1–5].

A very common type of plastic used for packaging is polystyrene. In the case of land filling, it is fundamentally non-biodegradable and takes hundreds of years to degrade, whereas other disposal or treatment options have harmful environmental effects. Polystyrene is made up of 98% air and only 2% polystyrene as a result of expandable polystyrene foam processing, and its base material is styrene monomer [6]. Polystyrene foam represents 0.1% of total municipal solid waste [7]. This material is known to have qualities like sound absorption, high thermal conductivity, and light weight, which make it an excellent additive to concrete [8]. Recycling and reusing waste materials is seen as the most environmentally friendly solution to the disposal issue. The waste product polystyrene (PS) is one example. A thermoplastic material called polystyrene has the potential to make lightweight concrete by replacing the conventional aggregate in concrete [9]. Low-density concretes needed for building applications can be made with polystyrene aggregate, and it can also be used for other specialized purposes like sub-base material for roads, railway track beds, the construction of floating marine structures and sea fences, energy absorption for the defense of buried military structures, and fenders on offshore oil platforms. Additionally, polystyrene aggregate concrete was shown to be fire-resistant, making it an excellent material for thermal insulation in building construction [10]. The effects of adding different types and dosages of polystyrene foam, both commercial and recycled, on the physical and mechanical properties of Portland cement mortars have been studied previously. These investigations have found that with a high amount of polystyrene foam, it is possible to produce mortars with mechanical properties suitable for use in masonry, rendering, and plaster mortars [11].

The objective of this paper is to determine the slump, water absorption, air content, density, flexural strength, modulus of elasticity, free shrinkage, and compressive strength of plain concrete containing polystyrene foam waste (WPEF) as a partial replacement for fine aggregate in relation to the percentage of polystyrene waste incorporated. In addition, the scope of the study is to compare the mechanical properties of plain concrete with polystyrene foam waste and observe which percentage of replacement is most appropriate in construction applications.

2. Materials and methods

2.1 Materials

The cement used in this investigation was ordinary Portland cement (OPC), complying with the standard LSS-340-09 [12]. Tab water was used, which was obtained from one of the water desalination plants in the city of Al-Khums. According to standard BSI 812-1995 [13], natural sand with a maximum size of 1.2 mm was used as a fine aggregate, and it was collected from Zlitan quarry. The sand has a 2.85 fineness modulus, a 2.6 specific gravity, and a 0.83% water absorption. The coarse aggregate (crushed sedimentary aggregate) of different maximum sizes, viz., 19 mm and 14 mm, was complying with the standard BSI 812-1995 [13], obtained from the quarries of the Al-Alous region located on the outskirts of the city of Al-Khums. The coarse aggregate (gravel) has a specific gravity of 2.75, water absorption of 0.47 % and a bulk density of 1542 kg/m^3. Table 1 shows the gradation of fine and coarse aggregates used in this study. Waste polystyrene foam (WPSF) used in this study was supplied from landfills located in the city of Al-Khums. WPSF had a loss of ignition of 100% and water absorption by immersion after 28 days of between 1.5% and 3% volume. Ground WPSF was obtained by mechanical grinding and sieving after crushing (Fig. 1). 100% of the ground WPSF particles passed through a 2.36 mm sieve, and the specific gravity was 0.025.

Table 1: The gradation of used aggregate.

Sieve size	Cumulative passing (%)	
	Natural sand	Coarse aggregate
19 mm	100	100
14 mm	100	56.45
10 mm	100	36.73
5 mm	100	1.01
2.36 mm	100	0
1.18 mm	97.12	0
0.6 mm	86.45	0
0.3 mm	62.14	0
0.15 mm	2.92	0
0.075 mm	0.74	0

Fig. 1: Photograph showing the aspect of WPSF.

2.2 Mix proportions

In order to produce structural WPTP concrete, natural sand was replaced with WPTP by 10%, 20%, and 30% by volume. The details of mixture proportions are illustrated in Table 2. The standard mixture was one of four concrete mixtures that were developed..

Table 2: Mixture proportion.

Mix ID	Cement (Kg/m^3)	Water (Kg/m^3)	Sand (Kg/m^3)	Gravel (Kg/m^3)	WPSF volume (%)
M-0	330	198	725	1088	0
M-10	330	198	718	1088	10
M-20	330	198	711	1088	20
M-30	330	198	704	1088	30

All the materials were mixed together by adding about half of water while mixing goes on for 1 minute. The remaining water was added to the mixture and continued mixing it for 3 minutes [14]. Fresh concrete tests, i.e., air content and slump tests, were carried out immediately after the completion of the mixing. According to each test for hardened concrete, the concrete mixes were cast into molds, and after the specimens hardened, they were cured at ambient temperature and tested on a specific day.

3.3 Test procedure

According to ASTM C185-15 [15], the air content of fresh concrete mix was investigated. This test was conducted on fresh concrete containing different contents of WPSF to determine the percentage of air voids. The concrete slump test is to determine the workability or consistency of the WPSF concrete mix. The slump test is the most simple workability test for concrete because it provides an immediate result. In this study, the slump test is carried out as per procedures mentioned in ASTM C143 /C143M [16].

The density test was accomplished at the age of 28 days, following BS 1881-114 [17] and ASTM C642-13 [18]. The specimen, after 28 curing days, was taken out for measuring its (bulk) density. The mass of the specimen was weighed, and the dimensions of the specimen were also measured to calculate the volume, The mass density was then calculated by the mass weight divided by the volume. For the water absorption test, the absorption of water by concrete specimens was determined by measuring the increase in mass resulting from the absorption of water. The water absorption values are the average of three specimens with a size of $100\times100\times100$ mm^3. After the curing period, specimens were dried in an oven at a temperature of 80 °C until a constant weight was attained. This is because WPSF is extremely sensitive to thermal degradation when subjected to relatively high temperatures. These were then immersed in water, and the weight gain was measured at regular intervals until a constant weight was reached. The water absorption is given by [19]:

$$\text{Water Absorption (\%)} = \left(\frac{W_s - W_d}{W_d}\right) \times 100 \quad \ldots..(1)$$

Where $\mathbf{W_s}$ and $\mathbf{W_d}$ are the saturated and dry weight of specimens, respectively.

The compressive strength of mix proportions with different WPSF volumes was evaluated according to BS 1881-116:1983 [20], with a loading rate of 70 kN/min, by using cubic specimens of size 100×100 ×100 mm^3 at ages corresponding to 7 and 28 days after water curing (Fig. 2). The flexural strength is determined by conducting the test method of ASTM C78/C78M [21] (third-point loading or 4-point bending test). Prisms with sizes of 100 mm × 100 mm × 400 mm were tested (Fig. 2).

Fig. 2: Compression and flexural test specimen.

The flexural strength at 7 and 28 days was determined by using a four-point loading test. The specimens rest on two supports, and half of the load is applied at each of the third of the span length. The specimen was loaded at a constant rate of 2.3 KN/min until the failure.

The modulus of elasticity of the studied WPSF concrete mixtures was found according to the standard ACI 318-08 [22], which gives the following expression for the modulus of elasticity of normal weight concrete:

$$E_c = 4700\sqrt{f_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where;
$\boldsymbol{E_c}$ = static modulus of elasticity.
$\boldsymbol{f_c}$ = compressive strength.

The free shrinkage of WPSF specimens was tested according to ASTM C157/C157M-08 Stranded [23]. The size of the specimen was 100 mm ×100 mm ×400 mm (Fig, 3a).

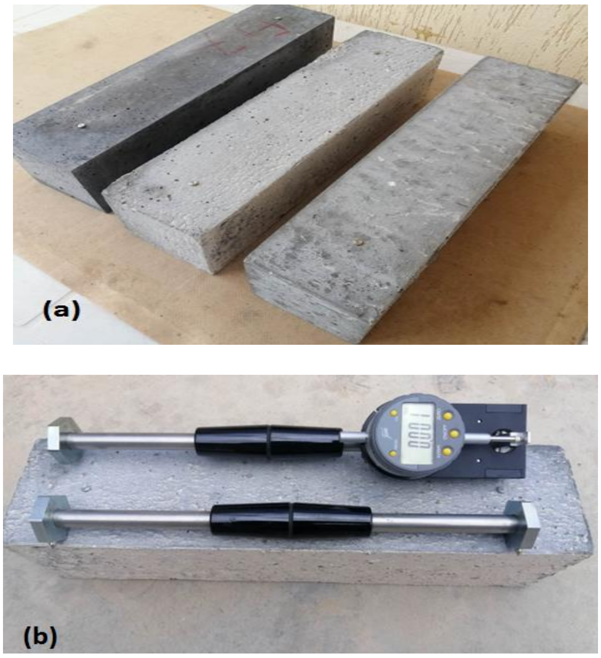

Fig. 3: (a) Free shrinkage specimens **(b)** Digital strain gauge.

To measure shrinkage strains along the length of the specimens, two pairs of stainless steel discs of gauge length (L_0) 25 mm were fixed at both ends of the specimens, so that there is a pair of every two opposite surfaces. A digital strain gauge with a precision of 10^{-3} mm was used (Fig. 3b). The specimens were dried at room temperature for 56 days. Subsequent shrinkage readings were taken after 3, 5, 10, 15, 20, 30, 40 and 56 days. The initial length was recorded as (L_1) and the subsequent length (L) was measured periodically. The free shrinkage is expressed by the following:

$$\text{Free shrinkage } (\varepsilon_f) = \left(\frac{L_1 - L}{L_0}\right) \times 100 \quad \dots\dots\dots..(3)$$

In order to evaluate the effect of WPSF on the acoustic characteristics of plain concrete, such as sound transmission, an ultrasonic pulse velocity test was approved. At age of 7 and 28 days, the average ultrasonic pulse velocity was calculated. This test was conducted in accordance with ASTM C597-09 Standard [24].

4. Results and discussion

4.1 Slump and air content

The slump of concrete specimens containing different percentages of WPSF is presented in Fig. 4. In general, mixes produced with WPSF experienced a slump. The results indicate a sharp reduction in slump at a percentage of sand replacement between 10% and 30%. With a replacement level of 10%, 20%, and 30%, the concrete mix slump values were about 65 mm, 60 mm, and 52 mm, respectively; i.e., when the content is increased from 10% to 30%, the slump is reduced by 45% to 67 %, meaning the slump is decreased as the content of WPSF is increased. The reason may be due to the large size of polystyrene foam grains compared to sand grains. As well as increasing the absorption of water in mixtures containing WPSF. However, the results obtained in this test are consistent with a previous study conducted by Kin and Ariffin [25].

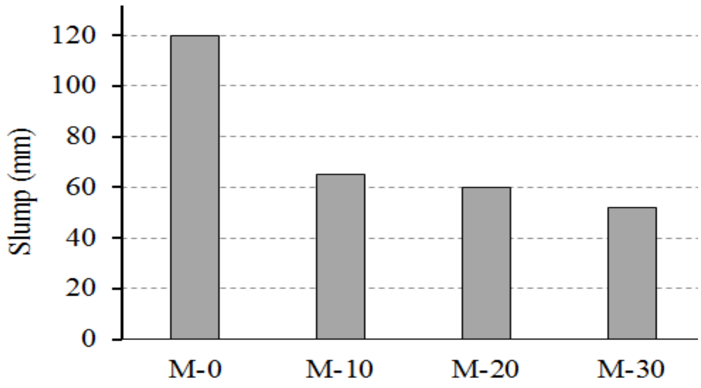

Fig. 4: Effect of percentage (%) replacement of WPSF on concrete slump.

The air content of concretes containing 0, 10, 20, and 30% WPSF is presented in Fig. 5.

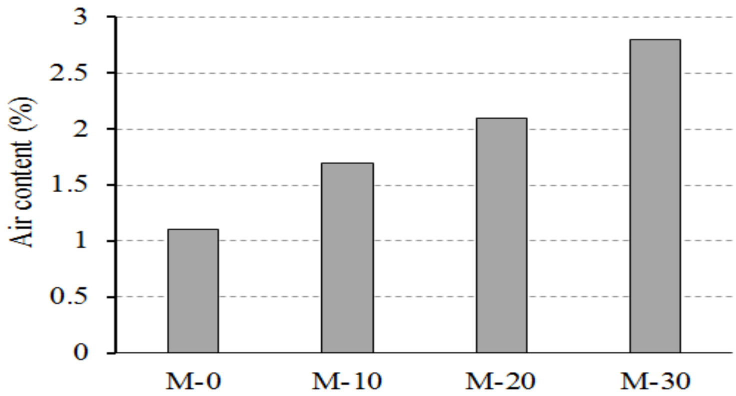

Fig. 5: Effect of percentage (%) replacement of WPSF on air content of concrete.

The results show that the incorporation of WPSF caused an increase in the air content of concrete, depending on the level of replacement with sand. The air content of the WPSF concretes decreased by 53%, 120%, and 164% at replacement level 10%, 20%, and 30%, respectively.

Such a result allows for justifying the decrease in density in the hardened stage. This behavior may be explained by the fact that the WPSF increases total porosity by affecting the air content of mixtures and may contribute significantly to the formation of air voids in the fresh concrete containing the WPSF, resulting in lower density and thermal conductivity. In addition, the surface and inside of WPSF particles caught molecules of air that entered the fresh concrete, leading to an increase in air content [26]. However, the effect of incorporating different levels of WPSF on the mechanical properties of fresh concrete, such as slump and air content, is almost identical to that of those containing rubber residue [26].

4.2 Water absorption and density

Figure 6 illustrates the water absorption of concrete containing varying amounts of WPSF. It can be observed that the concrete with a higher volume of WPSF, showed higher water absorption. The percentage of increase was about 54%, 91%, and 154% when the percentage of sand replacement was 10%, 20%, and 30%, respectively. The water absorption mainly increased as a result of the combination of the highly porous interfacial transition zone between the WPSF and cement paste of the mixture [27]. Due to the difference in the surface of the WPST grains compared to the sand grains, when mixed with water, the volumetric paste content is increased. In addition, the surface area surrounding the grains decreases with the increase in the amount of WPSF, leading to a reduction in the amount of cement paste surrounding the grains. When decreasing the amount of paste, the voids or pores in the concrete increase, and so does the water absorption [19].

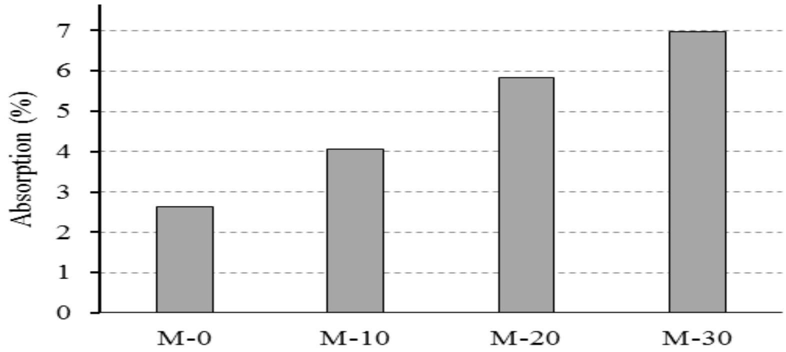

Fig. 6: Effect of percentage (%) replacement of WPSF on water absorption content of concrete.

The inclusion of WPSF to the concrete reduces its density almost by the same percent as its addition, as shown in Fig. 7. The inclusion of WPSF to concrete by 10% causes a reduction of 7% in its density. While this reduction in weight becomes almost 11% when the WPSF content is 30%.

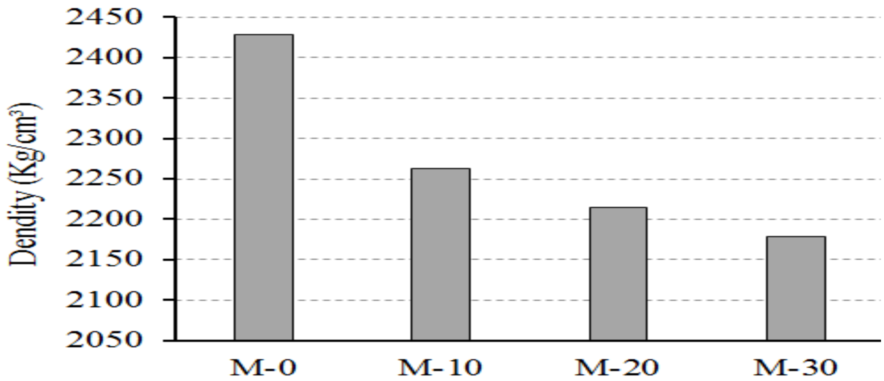

Fig. 7: Variation of concrete density with WPSF content.

The decrease in the density of concrete with the increase in WPSF content can be attributed to the weight of the WPSF, which is about 98% air [28]. Thus, there will be a decrease in density due to the increase in air content in the concrete. There is another reason related to the first, which is that the density of WPSF is much lower than that of natural sand. When more sand is replaced by WPSF, the density of concrete is lower. The results obtained in this study show similar results to those obtained by Herki and Khatib [27] and Askar et al. [28]. According to their study, as the replacement level of expanded polystyrene aggregate increased, the density of the concrete reduced. This is due to the fact that aggregate made of expanded polystyrene has a far lower density than aggregate made of natural materials.

4.3 Compressive strength and modulus of elasticity

The compressive strength and modulus of elasticity for concrete containing varying amounts of WPSF at the ages of 7 and 28 days of curing are shown in Figures 8 and 9. The relationship between compressive strength and modulus of elasticity of concrete is generally direct, meaning that as compressive strength increases, modulus of elasticity also tends to increase. This relationship is based on the fact that both properties are influenced by the same underlying factors, such as the density, porosity, and composition of the concrete. Therefore, the discussion of the results related to compressive strength corresponds to what will be mentioned in the results of the modulus of elastic. At both ages (7 and 28 days), the results show that the incorporation of WPSF caused a reduction in the compressive strength of concrete depending on the level of replacement with natural sand. The mixes containing 10%, 20%, and 30% WPSF have shown a decrease in compressive strength at 7 days of approximately 8%, 18% and 23%, respectively, in relation to the reference mortar. After 28 days of curing, the percentage reduction is almost 11%, 15%, and 25%, respectively.

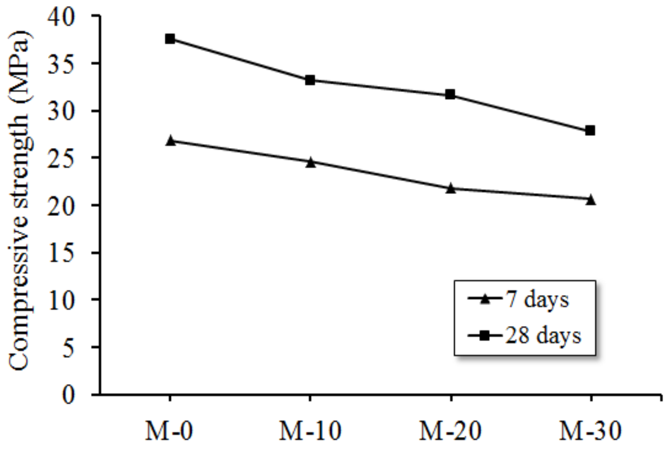

Fig. 8: Compressive strength of concrete at 7 and 28 days.

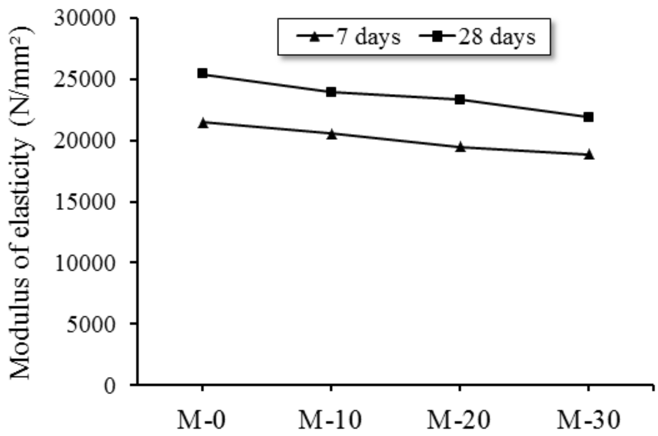

Fig. 9: Modulus of elasticity of concrete at 7 and 28 days.

This reduction may be associated with the increase in air content in the fresh state and because WPSF has a low density. Another reason for the decrease in compressive strength as well as modulus of elasticity is the replacement of natural sand with WPSF and the resulting increase in the surface area of fine particles of WPSF, which can lead to weakening of the interfacial zone between the WPSF and the cement paste [7]. The WPSF fills in the gaps left by the absence of natural sand. In addition, the compressive strength of polystyrene is lower than that of natural sand [29]. This will lead to a decrease in the compressive strength by increasing the WPSF. However, despite the decrease in compressive strength at 28 days for the mixture containing a 30% percentage of natural sand replacement, this mixture is still very suitable for construction applications.

4.4 Flexural strength

The flexural strength of concrete with different percentages of WPSF as sand replacement at the ages of 7 and 28 days is shown in Figure 10.

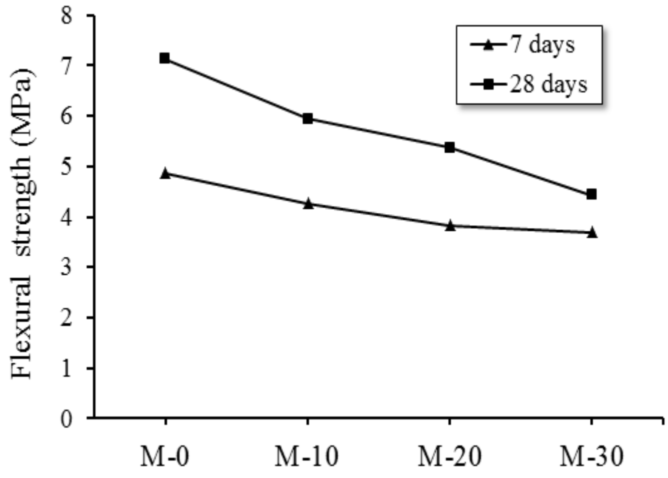

Fig. 10: Flexural strength of concrete at 7 and 28 days.

The results showed that WPSF had a remarkable influence on the flexural strength of plain concrete. Comparing with the control concrete, the results of the flexural strength test of WPSF concrete follow the same trend as the compressive strength test results: as the amount of WPSF in the mixture increases, the flexural strength decreases.

The reason for the decrease in flexural strength with an increase in the amount of WPSF is the same as explained in the discussion of the results of the compressive strength test. However, these results agree with a previous study conducted by Salahaldeen and Al-Hadithi [29] on the flexural strength of concrete made with expanded polystyrene.

4.5 Free shrinkage

Figure 11 shows the development of the free shrinkage strains with the measurement time for concrete containing varying amounts of WPSF. Therefore, one objective of the current study was to provide a clearer understanding of the free shrinkage of WPSF concrete by monitoring it over a period of time (i.e., 56 days). The majority of free shrinkage, as determined by the findings of the current study, took place in the first 30 days. Beyond that time, the free shrinking rate decreased until the 56-day monitoring period's completion. It can be observed that high WPSF replacement levels in concrete make it less resistant to shrinkage. This could be explained by the presence of fine aggregates that may restrain the amount of shrinkage of the cement paste, and this effect gradually fades with increasing the amount of WPSF in the concrete mixes [30]. The low stiffness and compressibility of polystyrene particles, which provide very little restraint to the shrinkage of paste [31]. As was previously noted, WPSF is a compressible material with a high porosity, which indicates more water can wick through its pores (up to 7%), decreasing its mechanical and durability properties [27]. Generally, polystyrene is a lightweight material that has a low density and is highly porous. When polystyrene beads are mixed with concrete, they create voids within the material that can trap air and moisture. As the concrete cures and dries, the trapped air and moisture can escape, leaving behind small voids in the material. These voids can cause the concrete to shrink and contract, leading to cracking and other forms of damage [27]. Similar findings were reported by Herki and Khatib [27] and Tang and Nadeem [30].

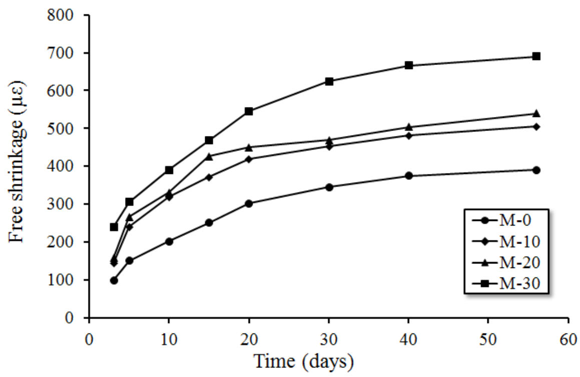

Fig. 11: Free shrinkage of concrete containing varying amounts of WPSF at different times.

4.6 Ultrasonic pulse velocity (UPV)

The UPV values of concrete containing varying amounts of WPSF at 7 and 28 days are presented in Figure 12. At both ages (i.e., 7 and 28 days), it can be observed that the higher the percentage of WPSF replacement accompanied the decrease in the UPV.

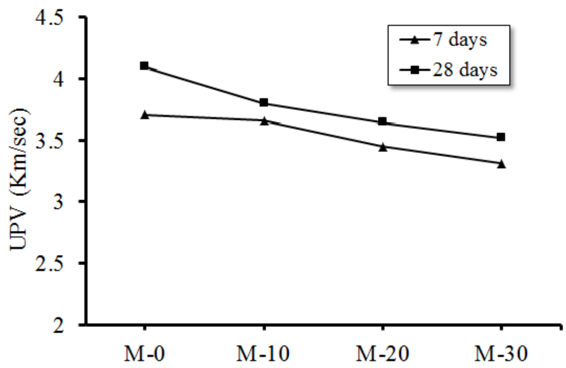

Fig. 12: UPV of concretes containing varying amounts of SPS at 7 and 28 days.

The trend is similar to that of concrete compressive and flexural strengths in that an increase in WPSF in concrete leads to a decrease in UPV. The UPV values of the concretes containing 30% WPSF at 7 and 28 days of age decreased by 10% and 14%, respectively, compared to the control mixture. The ultrasonic pulse velocity of a material is determined by its density. When WPSF is incorporated into concrete, it reduces the overall density of the concrete, which in turn decreases the UPV that can pass through it. Overall, adding WPSF to concrete can improve its acoustic and thermal properties, making it more effective at absorbing sound and temperature. This can have a range of structural applications.

5 Conclusions

The following are the conclusions of this study:

- The incorporation of WPSF caused a sharp reduction in the slump of the concrete at replacement levels between 10% and 30%.
- The air content of the WPSF concrete increased with the level of replacement, resulting in a lower density.

- The concrete with a higher volume of WPSF showed higher water absorption. The inclusion of WPSF in concrete reduces its density.
- The incorporation of WPSF caused a reduction in the compressive strength and modulus of elasticity of the concrete depending on the level of replacement with natural sand. After 28 days of curing, the mixture containing a 30% percentage of sand replacement still had suitable compressive strength for construction applications.
- The flexural strength of WPSF concrete decreased as the amount of WPSF in the mixture increased.
- High WPSF replacement levels in concrete made it less resistant to free shrinkage, with the majority of free shrinkage taking place in the first 30 days.
- Increasing the WPSF content in concrete led

to a higher UPV, which contributes to improving thermal and acoustic insulation.

Overall, the study suggests that the use of WPSF in concrete can have both positive and negative effects on various properties of concrete. The results should be considered when designing concrete mixtures, and further research is needed to better understand the potential of WPSF as a sustainable construction material.

References

[1] Altwair, N., M. & Sryh, L., S., (2020), Effect of Sawdust on The Mechanical Properties of Mortar Using Local Materials, Third Conference for Engineering Sciences and Technology, 1-3 December 2020 /Alkhoms –Libya. DOI: http://dspace.elmergib.edu.ly/xmlui/handle/123456789/208.

[2] Akcaozoglu, S. & Atis, C.D., (2011), Effect of Granulated Blast Furnace Slag and Fly Ash Addition on the Strength Properties of Lightweight Mortars Containing Waste PET Aggregates. Constr Build Mater, **25**, 4052–8. DOL: https://doi.org/10.1016/j.conbuildmat.2011.04.042

[3] Kockal, N.U & Ozturan, T., (2011), Strength and Elastic Properties of Structural Lightweight Concretes. Mater Des ,**32**, 2396–403. DOL: https://doi.org/10.1016/j.matdes.2010.12.053

[4] Altwair, N.M., Megat Johari, M.A., and Saiyid Hashim, S.F., (2012), Flexural Performance of Green Engineered Cementitious Composites Containing High Volume of Palm Oil Fuel Ash, Const. Build. Mater., **37**, 518–525. DOI: https://doi.org/10.1016/j.conbuildmat.2012.08.003.

[5] Altwair, N.M., Johari, M.A.M., and Hashim, S.F.S., (2013), Influence of Treated Palm Oil Fuel Ash on Compressive Properties and Chloride Resistance of Engineered Cementitious Composites. Mater. Structu., **47,** 667–682. doi:10.1617/s11527-013-0087-4.

[6] Pczieczek, A., Schackow, A., Effting, C., Dias, T. F. & Gomes, I., (2018), Properties of Mortars Containing Tire Rubber Waste and Expanded Polystyrene (EPS), Urb. Enviro. Eng., **11**, 219-225. DOI: 10.4090/juee.2017.v11n2.219225

[7] Ferrándiz-Mas, V. & García-Alcocel, E., (2013), Durability of Expanded Polystyrene Mortars, Constr. Build. Mater., **46**, 175-182. DOI: https://doi.org/10.1016/j.conbuildmat.2013.04.029

[8] Ubi, S. E., Ewa, D. E., Bessong, A. R. & Nyah, K. D, (2022), Effects of Incorporating Expanded Polystyrene in Concrete Construction., Buil. Constr. Plan. Res., **10**, 79-101. DOL: 10.4236/jbcpr.2022.103004.

[9] Herki, B. A. & Khatib, J. M., (2013), Lightweight Concrete Incorporating Waste Expanded Polystyrene, Adv. Mate. Res., **787**, 131-137. DOI: https://doi.org/10.4028/www.scientific.net/AMR.787.131.

[10] Babu, K.G., Babu, D.S. & Wee, T.H., (2006), Effect of Polystyrene Aggregate Size on Strength and Moisture Migration Characteristics of Lightweight Concrete. Cem. Conc. Comp., **28**, 520-527.DOI: https://doi.org/10.1016/j.cemconcomp.2006.02 .018

[11] Ferrándiz-Mas V & García-Alcocel E., (2012), Physical and Mechanical Characterization of Portland Cement Mortars Made with Expanded Polystyrene Particles Addition, Mater. Constr, **62**, 547–66. DOI: 10.3989/mc.2012.04611.

[12] LSS 340-09, Libyan Standard Specifications in Portland Cement, Libyan National Center for Standardization and Metrology, 2009.

[13] BSI 812-95, Methods of Sampling and Testing of Mineral Aggregates, Sands, Fillers, Part 1, British Standard Institution (BSI), London, 1995.

[14] Mazizah, E. M., Robert T., Razak, A., Kifli, A. Z. & Nisa A., (2022), Compressive Strength of Concrete Containing Expanded Polystyrene Styrofoam (EPS) Concrete and Partial Cement Replacement of Fly Ash and Silica Fume, Mechan. Eng., **11**, 301-317. DOI: https://doi.org/10.1177/2633366X2091.

[15] ASTM C185 – 15, Standard Test Method for Air Content of Hydraulic Cement Mortar, ASTM International: West Conshohocken, PA, USA, 2015.

[16] ASTM C143/C143M-00. Standard Test Method for Slump of Hydraulic-Cement Concrete, ASTM International: West Conshohocken, PA, USA, 2000.

[17] BS 1881-114, testing concrete - Methods for Determination of Density of Hardened Concrete, British Standard, Part 114, British Standard Institution (BSI), London, 1983.

[18] ASTM C642, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, ASTM International: West Conshohocken, PA, USA, 2013.

[19] Bengin M. A. H., (2017), Absorption Characteristics of Lightweight Concrete Containing Densified Polystyrene, Civi. Eng. J., **3**, 594-609. DOI: 10.28991/cej-2017-00000115

[20] BS 1881-116, Testing concrete. Method for Determination of Compressive Strength of Concrete Cubes, Fillers, Part 1, British Standard Institution (BSI), London, 1983.

[21] ASTM C78/C78M – 16, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third- Point Loading) ASTM International: West Conshohocken, PA, USA, 2016.

[22] ACI 318-08, (2008), Building Code Requirements for Structural Concrete and Commentary. American Concrete Institute.

[23] ASTM C157/C157M-08 Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete, ASTM International, West Conshohocken, PA, USA, 2008.

[24] ASTM C597–09, Standard Test Method for Pulse Velocity Through Concrete, ASTM International, West Conshohocken, PA, USA, 2009.

[25] Kin, L. W. & Ariffin, M. A. M., (2016), Strength Properties of Expanded Polystyrene Concrete and Cold Formed Steel Wall Frame Composite, Mater. Scie., **11**, 126-173. DOI: 10.36108/laujoces/9102/20(0121

[26] Roman C. , Tomáš T. , Fládr, J. & Petr B., (2017), Mechanical properties and durability of crumb rubber concrete, Mater. Sci. Eng.g, **236**, 1-7. DOI: 10.1088/1757-899X/236/1/012093

[27] Herki, B. A. & Khatib, j., (2016), Valorisation of Waste Expanded Polystyrene in Concrete Using a Novel Recycling Technique, Europe. J. Environ. Civi. Eng., 1-19. DOI: doi.org/10.1080/19648189.2016.1170729

[28] Askar, L. K., Albarwary, I. H. & Askar, M. K., (2019), Use of Expanded Polystyrene (Eps) Beads in Silica-Fume Concrete, J. Univ. Duhok, **22**, 30-38. DOI: https://doi.org/10.26682/sjuod.2019.22.1.5

[29] Salahaldeen, A. S., & Al-Hadithi, A. I., (2022), The Effect of Adding Expanded Polystyrene Beads (EPS) on the Hardened Properties of Concrete, Eng. Tech. Appl. Sci. Rese., **12**, 9692-9696. DOI: https://doi.org/10.48084/etasr.5278

[30] Tang, W.C., Lo, Y. & Nadeem, A., (2008), Mechanical and Drying Shrinkage Properties of Structural-graded Polystyrene Aggregate Concrete, Cem. Conc. Comp., **30**, 403–409. DOI: https://doi.org/10.1016/j.cemconcomp.2008.01.002

[31] Elsalah, J., Al-Sahli, Y., Akish, A., Saad, O., & Hakemi, A., (2013). The Influence of Recycled Expanded Polystyrene (EPS) on Concrete Properties: Influence on Flexural Strength, Water Absorption and Shrinkage, AIP Conference Proceedings, **1569**, 181–185. DOI: https://doi.org/10.1063/1.4849254