Journal of Engineering Research, Volume 25, Number 3, September 2020

An Investigation on the Use of Expanded Polystyrene as a Partial Replacement of Fine Aggregate in Concrete

U. T. Igba[1], *S. O. Ehikhuenmen[2], S. O. Oyebisi[3] and N.O. Oloyede[1]

[1] Department of Civil Engineering, Federal University of Agriculture Abeokuta, Ogun State, Nigeria

[2] Department of Civil and Environmental Engineering, University of Lagos, Lagos, Nigeria.

[3] Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria.

*Corresponding author email: sehikhuenmen@unilag.edu.ng

Abstract

The construction sector in Nigeria is looking for alternative materials due to the consistent increase in the cost of building materials. Expanded Polystyrene (EPS) material derived from the distillation process of crude oil. It is 100% recyclable, bacteria and age resistant, lightweight with low moisture absorption and possess an excellent cushioning property. This paper focuses on the use of EPS as partial replacement of quarry dust in concrete to carry light loads. Five replacement increments were compared at 0%, 0.25%, 0.5%, 0.75% and 1.0% for EPS with mix ratio of 1:2:4 and water-cement ratio of 0.55. Slump, compaction factor and, compressive strength tests were conducted using slump and compaction factor test apparatus on fresh and cured concretes to determine how the incorporation of EPS as a replacement of fine aggregate would affect the development of strength in the mixes. The workability result of the slump and compaction factor test value decreased as the percentage replacement of EPS increased from 0 to 1 % leading to a less workable concrete since the increment in percentage replacement led to a reduction in the bonding property of the concrete. The optimum blend was at 0.25 % replacement of fine aggregate with EPS. The replacement of EPS showed a positive application as an alternative material in building non-structural members. It was concluded that the expanded polystyrene concrete (EPC) can best be used in non-structural applications like solid ground floors and lightweight concrete in ambient temperature.

Keywords: Compressive strength, Expanded polystyrene concrete, Fine aggregate

1.0 INTRODUCTION

EPS is one of the most well-known lightweight materials utilized in building and development purposes in numerous nations around the globe. In Australia, alone EPS compensates for about 65% as far as use (Expanded Polystyrene Australia, EPSA, 2016). Stark *et al.* (2004) announced that EPS geofoam which was presented as a very lightweight cellular geosynthetic material contained a few favourable qualities for application in highways and geotechnical Engineering. EPS geofoam has been included in construction work such as backfill for retaining walls, bridge abutments and as sub grade for roads and highways around the world.

Ray *et al.* (2014) investigated that the unit weight of EPS installed structure arrived at 35% less than the conventional concrete structure and the pre-assembled unit reduces the general expense of the structure extensively. Ede and Ogundiran (2014) researched the utilization of EPS material in building and development projects. It was accounted for that EPS utilized for building development was of different sorts and sizes with the most well-known ones being for divider boards and for slab that was raised with steel meshes. The steel wire mesh served as reinforcement support. EPS material is impervious to fire and tremors. It is an all-climate proof construction and maintenance free. Modular in nature and pre-built for accuracy and disentangled construction. Suhad *et al.* (2016), communicated the way that the dry density diminishes with an expansion in EPS total substance in concrete. Their investigation varied EPS substitution in concrete at 5 %, 10 %, 15 %, and 20 %, however the dry density increased with age for each concrete mixture at all curing ages. Kuhail (2003) characterized EPS as a lightweight cellular plastic material comprising of fine spherical shaped particles which consisted of about

98% air and 2% polystyrene. Saradhi *et al.* (2005) researched the utilization of EPS as a material that can be granulated and used to replace typical aggregate in concrete to produce EPC which helps in the minimization of EPS beads thereby preventing the disposal of EPS. The polystyrene molecule is uniform in shape and size, the concrete ranges from that of no-fines concrete with density 300 kg/m^3 or less to that of completely compact concrete with density 1000kg/m^3 or more.

Nawy (2008) inferred that the shape, size, grading and surface texture of aggregate, coarse/fine aggregate proportion, as well as aggregate/ cement proportion, influence the workability of concrete. Mehta and Burrows (2001) characterized EPC as one of the most usually utilized lightweight concrete in the building industry as of late. It utilizes low quality materials with great energy-absorbing characteristics. EPS is good in thermal and acoustic insulation properties and thus, it is for the most part utilized in non-structural applications, for example, precast rooftop, precast divider boards, and lightweight infill blocks. Ordinary concrete is made of natural coarse aggregates, natural fine aggregates, Portland concrete and water and, obviously, every last one of these primary ingredients, to an alternate level, has an environmental impact. Aaboe and Frydenlund (2011) reported that although a 100 years lifespan is stipulated for EPS when used in construction projects. The use of EPS geofoam in projects for the past 30 years, showed that there has been no indication of material deterioration, as the material remains intact after many years in use. The compressive strength tests conducted on these samples showed that there was no overall reduction in compressive strength. The research led by Horvath (1995) revealed that although EPS can absorb water despite its closed cellular structure, a rare case of deterioration occurred as a result of the absorption of water over a long period of time.

In previous studies, Aabo, (1987) and Tomasz *et al.* (2019) had used EPS as applications in pavement construction and building construction for fill materials, slope stability materials, thermal insulation materials as shown in Figure 1 to 3. This purpose of this paper is to investigate the usefulness of waste of Expanded polystyrene as a partial replacement of fine aggregate in concrete with the aim of converting waste to wealth.

Figure 1: EPS applied to reduce stress and settlement on underlying subgrades (Aaboe and Frydenlund, 2011)

Figure 2: EPS used in floating foundation (Aaboe and Frydenlund, 2011)

Figure 3: Excavation of a 24 years old EPS block used for embankment at Flom bridge in Oslo Norway. (Tomasz *et al.,* 2019)

2.0 MATERIALS AND METHOD

2.1 Materials

The materials and equipment used in this study are; metal cube mould (100 mm × 100 mm × 100 mm) compacting rod, slump test cone, concrete load testing machine (Hydraulic testing machine), EPS beads, crushed granite stone maximum size of 20 mm, quarry dust having passed through 4.75 mm sieve, Limestone Portland cement (LPC) of grade 32.5 N, hand trowel and a Vernier calliper. The crushed stone (granite) was sourced at a quarry site 70 15 'N, 30 25'E along Alabata Village, Abeokuta, Ogun State Nigeria, already graded and in the desired size of 12 mm. EPS beads shape and size range was Spherical and (1-3 mm diameter) respectively.

Figure 4: EPS beads

2.2 Method

2.2.1 The process of preliminary treatment for the constituents

The EPS was collected from a shopping centre in Ogunpa market in Ibadan, Oyo state. The samples were thoroughly cleaned before use, to ensure that the debris and other forms of impurities that could alter or influence the hydration and bonding of cement water paste were removed. The samples were then shredded to beads with the use of manual grater in the laboratory.

2.2.2 Tests

The material constituents for the concrete were subjected to various tests including size distribution, moisture content, specific gravity, slump test, compaction factor test, compressive test before the formulation of the concrete mixture.

2.2.3 Specific gravity

The specific gravity of the quarry dust and the EPS were carried out according to the standard of BS 1377-2 (1990) standard test for the specific gravity of soil solids by water pycnometer. The specific gravity was calculated as shown in Eq. 1.

$$\text{Specific gravity, } G_S = \frac{W_0}{W_0+(W_A-W_B)} \qquad (1)$$

Where,

W_0 = weight of sample of oven-dry soil

W_A = weight of pycnometer filled with water + sample

W_B = weight of pycnometer filled with water

2.2.4 Slump Test

The slump test was carried out under the provisions of BS EN 12350-2 (2000). The concrete slump test is an empirical test that measures the workability of fresh concrete. More specifically, it measures the consistency of the concrete in that specific batch. The slump values were recorded appropriately.

Figure 5: Slump test on fresh concrete

2.2.5 Compaction factor Test

The compaction factor test was carried out under the provisions of BS EN 12350-4 (2000). It is pertinent to note that the higher the value of the compacting factor the more workable is the mix and the lesser the hardened concrete strength. The compacting factor test is useful for defining the workability of the fresh concrete mixture was calculated as shown in Eq. 2.

$$\text{Compacting factor value} = \frac{W2-W1}{W3-W1} \qquad (2)$$

Where,

W_1 = Weight of empty cylinder

W_2 = Weight of partially compacted Concrete

W_3= Weight of fully compacted Concrete

2.2.6 Compressive Strength Test

The 45 Nos of cubes (100 mm) were produced in accordance with BS EN 12350-6 (2009), BS EN 12390-3, (2009) cured and tested at 7, 21, and 28 using a Compressive Testing machine with a capacity of 1500 KN at Federal Civil Engineering Building, University of Agriculture.

The compressive strength was calculated as shown in Eq. 3.

$$\text{Compressive strength } f = \frac{F}{A} \qquad (3)$$

Where,

f = Compressive strength (N/mm^2)

F = Failure load (N)

A = Area of concrete cube-face (mm^2)

Figure 6: Compressive strength test on cured concrete

2.3. Batching

2.3.1 Preparations of test samples

Weight batching method was used, and five batches were obtained for each replacement. Mass substitution of quarry dust with EPS are at percentages of 0 %, 0.25 %, 0.5 %, 0.75 % and 1 % for the five batches, respectively. The water content was kept constant at 0.55 for all batches. The mix ratio adopted was 1:2:4. The mix proportion by mass for each batch is presented in Table 1.

Table 1: Batch mix proportions for EPS replacement

Percentage Replacement (%)	Cement (Kg)	Quarry dust (Kg)	Granite (Kg)	EPS (g)
0.00	4.75	9.50	19.00	0.00
0.25	4.75	9.48	19.00	23.76
0.50	4.75	9.46	19.00	47.52
0.75	4.75	9.43	19.00	71.30
1.00	4.75	9.41	19.00	95.04

3.0 RESULTS AND DISCUSSION

3.1 Physical properties of aggregates

It was observed that quarry dust and EPS beads had uniformity coefficients (Cu) of 10.57 and 2.09 respectively while 0.7 and 0.9 for coefficient of curvature (Cc). Quarry dust used for this investigation was used as fine aggregate in the concrete mix and was within the confinement of BS 882-1992. In Figure 7, the particle distribution curve had a slight hump at the intermediate region of the curve, which portrayed a kind of soil in which a portion of the intermediate size particles were missing, referred to as gap-graded or skip-graded soil.

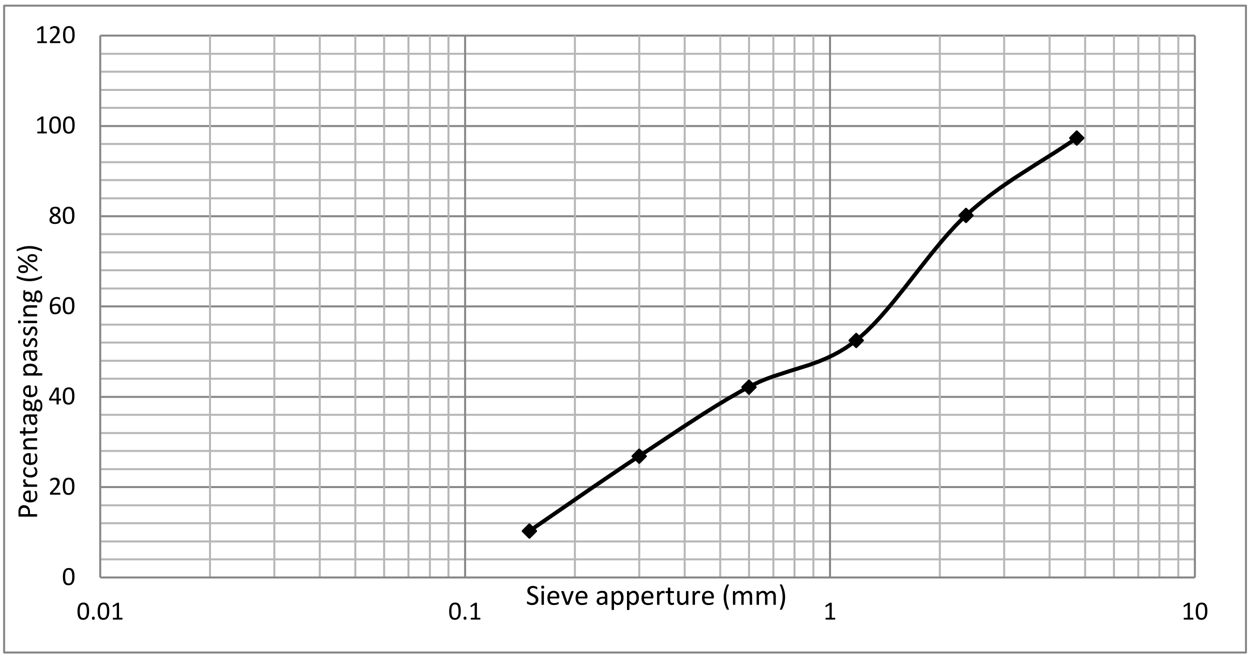

Figure 7: Quarry dust Particle Size Distribution Curve

According to Unified Soil Classification, from the result obtained above, it can be concluded that the quarry dust is well-graded.

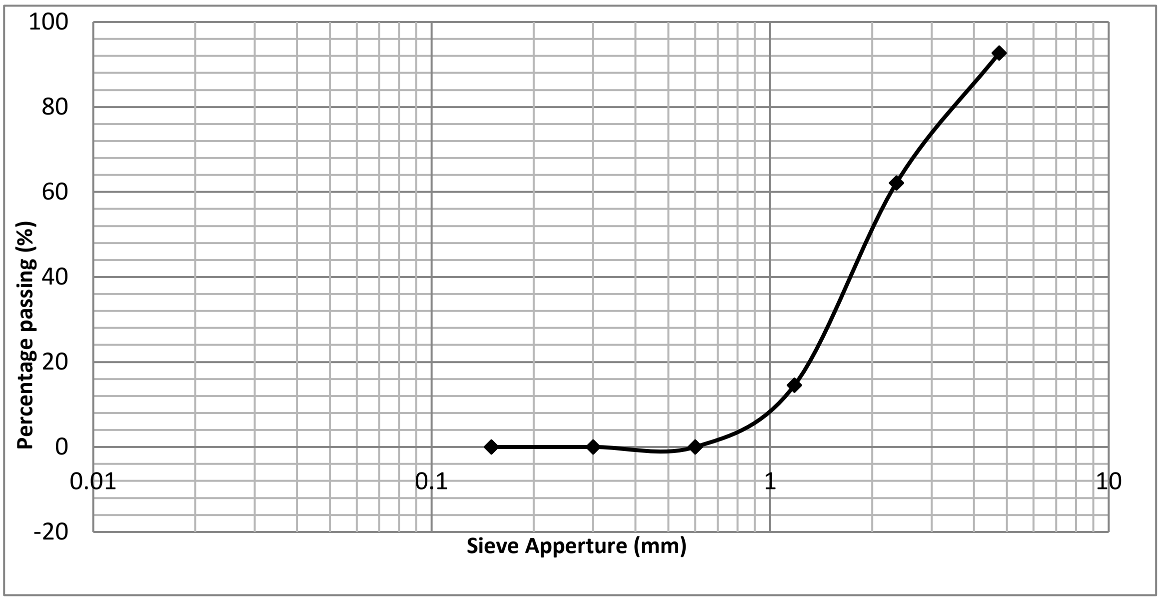

Figure 8: EPS beads Particle Size Distribution Curve

The EPS particles used for this study slightly deviated from BS 882 (1992) requirements with EPS particles not falling within the C, M and F additional limits for grading but satisfied the overall limits, which implied that EPS was coarser than quarry dust when replaced in the concrete mix. The particle size distribution curve in Figure 8 showed that the EPS particles had a steep curve, indicating the type of aggregate used which contained particles of almost the same size. Such aggregates are referred to as uniform aggregates.

3.2 Specific gravity result

Specific gravity is directly related to the relative density of the solid material made up of the constituent particles, not including the pore space within the particles that were accessible to water.

Table 2: Value of specific gravity for samples used

Type of sample	Specific gravity
Quarry dust	2.63
Expanded polystyrene	0.012

The result in Table 2 showed that the EPS was lighter than quarry dust. This, therefore, indicated that a lighter concrete was achieved when quarry dust (fine aggregate) was partially replaced by EPS beads.

3.3 Effect of EPS on the workability of concrete

Figure 9 revealed that there was a gradual reduction in slump with an increased amount of EPS in the concrete mix. This indicated that concrete became less workable with an increase in the percentage replacement of quarry dust with EPS particles, which may have attributed to major reason behind the improper bonding of the concrete with other constituents as shown in Figure 9 with reduced compressive strength values for 0.75 % and 1 % percentage replacement of quarry dust with EPS.

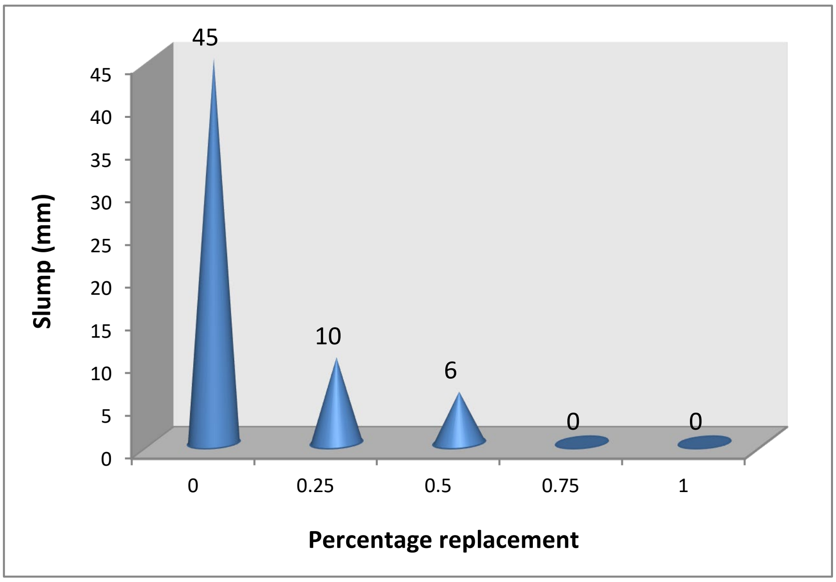

Figure 9: Slump value of EPC

For the EPS at 0.25% and 0.5 % replacement, the concrete mix was fairly workable while at 0.75% and 1% replacement, the concrete had zero slump. This result, therefore, showed that the concrete mix containing a higher percentage of EPS required higher water content to achieve a reasonable workability and flow characteristics.

Table 3: Compaction factor value for EPC

Percentage replacement	Compaction Factor
0	0.89
0.25	0.78
0.5	0.75
0.75	0.65
1.0	0.62

In Table 3, it was shown that as the percentage replacement increased from 0.25 to 1 the compaction factor value reduced from 0.78 to 0.62. This result, therefore, showed that as the concrete mix contained a higher percentage of EPS it required a higher quantity of water content to achieve reasonable workability and flow characteristics.

3.4 Effect of EPS on the density of concrete

The results presented in Table 4 revealed that increased EPS content led to a decrease in the density of concrete. At 28th-day, the expanded polystyrene concrete decline by 200 kg/m^3, 280 kg/m^3, 400 kg/m^3, and 600 kg/m^3 for 0.25 %, 0.50 %, 0.75 % and 1.0 % of EPS respectively when compared with the control. This affirms the findings of Elias et al. (1999) that EPS is an ultra-lightweight material that has a density of approximately 1/100th of other conventional fill materials.

Table 4: Determined dry density of concrete cube for EPS

Percentage replacement	Average weight and density of concrete cube (7 days curing)		Average weight and density of concrete cube (21days curing)		Average weight and density of concrete cube (28 days curing)	
	Weight (kg)	Density (kg/m^3)	Weight (kg)	Density (kg/m^3)	Weight (kg)	Density (kg/m^3)
0	2.59	2590	2.64	2640	2.70	2700
0.25	2.35	2350	2.40	2400	2.50	2500
0.50	2.25	2250	2.34	2340	2.42	2420
0.75	2.15	2150	2.25	2250	2.3	2300
1.0	1.7	1700	1.9	1900	2.1	2100

3.5 Effect of EPS on the compressive strength of concrete

The variations in the compressive strength of concrete due to the influence of EPS are presented in Figure 10. It was observed that the compressive strength increased with increase in curing age.

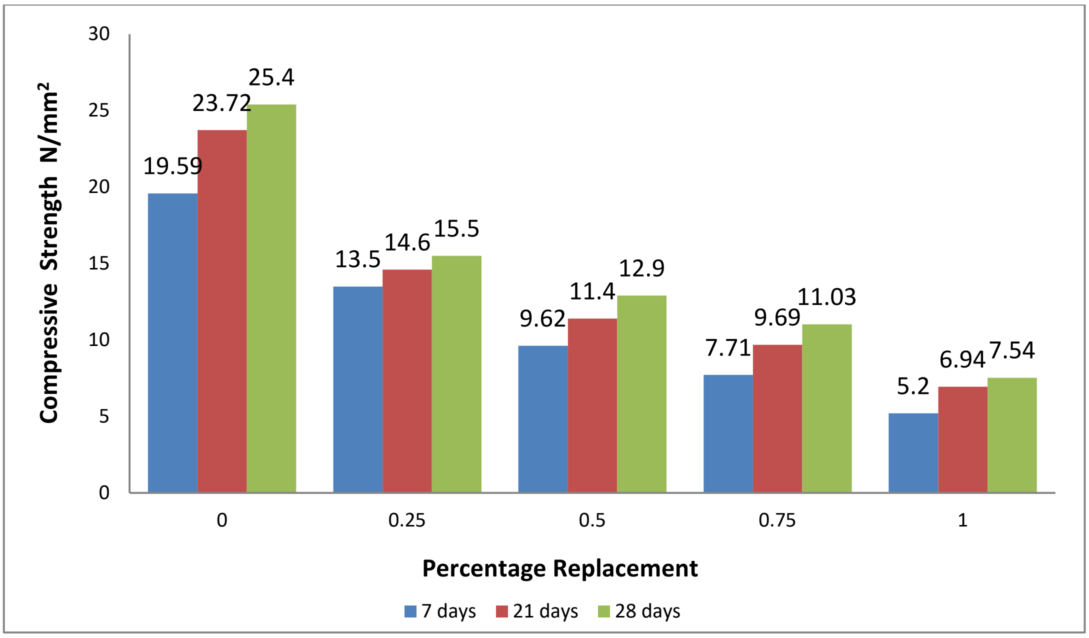

Figure 10: Compressive strength of EPC at different curing days

From Figure 10, it was observed that the compressive strength decreased with every addition of EPS content that was replaced with quarry dust at all ages. On the 7th-day, the optimum strength of percentage replacement was recorded at 0.25 with a value of 13.5 N/mm^2 while the least strength at 7th day was recorded at 1 with a value of 5.2 N/mm^2. At 21 days and 28 days, the optimum strength was recorded at 0.25 with values of 14.6 N/mm^2 and 15.5 N/mm^2 respectively while the least strength was recorded at 1 with values of 6.94 N/mm^2 and 7.54 N/mm^2 respectively, when compared to ordinary mix (control) of 25.4 N/mm^2. The result confirmed the work of Batayneh *et al.* (2007) that a decrease of compressive strength was a function of an increase in the plastic content.

4.0 CONCLUSION

From the research findings, the following conclusions can be made:

i. The slump value and compaction factor value decreased as the percentage replacement of EPS increased.
ii. The replacement of EPS showed a positive application as an alternative material in building non-structural members, and it also served as a solution to waste expanded polystyrene disposal. An increment in the percentage replacement of EPS reduced the density and compressive strength of concrete.
iii. The EPC containing 0.25% can best be used for non-structural applications for example in construction of walls, interior and exterior decorative mouldings. However, 0.75% and 1% replacement should not be used for non-structural purposes as it tends to fail easily under load.

REFERENCES

Aaboe, R. (1987). 13 years of experience with expanded polystyrene as a lightweight fill material in road embankments. *Norwegian Road Research Laboratory Publication* 61: 21–27.

Aaboe, R. and Frydenlund, T. E. (2011). 40 years of experience with the use of EPS geofoam blocks in road construction. *Proceedings of the fourth International Conference on Geofoam Blocks in Construction Applications,* Lillestrom, Norway.

Batayneh, M., Marie, I. and Asi, I. (2007). Use of selected waste materials in concrete mixes, *Waste Management*, 27**(12)**: 1870–1876.

BS 1377-2 (1990). British standard methods of test for soil for engineering purposes: classification tests. *British Standard Institution*, London.

BS 882 (1992). Specification for aggregates from natural sources for concrete. *British Standard Institution*, London.

BS EN 12350-2: (2000). A Method for Determination of Slump. *British Standard Institution*, London.

BS EN 12350-4: (2000). Testing fresh concrete. Degree of compactability. *British Standard Institution*, London.

BS EN 12350-6: (2009). Testing Fresh Concrete Density of Test Specimens. *British Standard Institution,* London.

BS EN 12390-3: (2009). Testing Hardened Concrete. Compressive Strength of Test Specimens. *British Standard Institution*, London.

Ede, A. N. and Ogundiran, A. (2014). Thermal Behaviour and Admissible Compressive Strength of Expanded Polystyrene Wall Panels of Varying Thickness," *Current Trends in Technology and Science*, 3**(2)**: 110 -117.

Elias, V., Welsh, J., Warren, J. and Lukas, R. (1999). Ground Improvement Technical Summaries. DTFH61-93-R-00145, *Federal Highway Administration*, U.S. DOT, Office of Technology Application.

Expanded Polystyrene Australia, EPSA (2016). www.epsa.org.au *International Organization for Standardization*. ISO Guide 73:2009 Risk Management vocabulary http://www.iso.org/iso/catalogue_detail?csnumber=44651

Horvath, J. S. (1995). Geofoam geosynthetic. *Horvath Engineering*, P.C., Scarsdale, New Work, USA.

Kuhail, Z. (2003). Mechanical Properties of Polystyrene-Lightweight Concrete. *Journal of The Islamic University of Gaza*, 11**(2)**: 93-114.

Mehta, P. K. and Burrows, R. W. (2001). Building Durable Structures in the 21st Century. *Concrete International*, 23**(3)**: 57-63.

Nawy, E. G. (2008). Concrete Construction Engineering Handbook. Boca Raton: CRC Press, https://doi.org/10.1201/9781420007657

Tomasz, M., Joanna, N. and Damian, B. (2019). Application of EPS Geofoam to a Soil–Steel Bridge to reduce Seismic Excitations. *Geosciences,* 9**(10):** 448.

Raj, R., Nayak, M. K., Akbari, M. A. and Saha, P. (2014). Prospects of expanded polystyrene sheet as green building material. *International Journal of Civil Engineering Research*, 5**(2)**: 145-150.

Saradhi, B. D., Ganesh, B. K. and Wee, T. H. (2005). Properties of lightweight expanded polystyrene aggregate concretes containing fly ash. *Cement and Concrete Research*, 35**(6)**: 1218–1223.

Stark, T. D., Arellano, D., Horvath, J. S. and Leshchinsky, D. (2004). Guideline and Recommended Standard for Geofoam Applications in Highway Embankments; NCHRP REPORT 529; *Transportation Research Board of the National Academies*: Washington, DC, USA.

Suhad, M. A., Dhamya, G., Maan, H., and Dunya, K. (2016). Effective replacement of fine aggregates by expanded polystyrene beads in concrete. *International Journal of Engineering Research and Science and Technology*, 5**(3)**: 45-53.