APPLICATIONS OF RECYCLED EXPANDED POLYSTYRENE (EPS) WASTE AS FILLER IN BUILDING MATERIALS

Yosra Al-Sahli, Jamaleddin Elsalah, and Hakemi Abdurrahman

Department of Materials & Metallurgical Eng., University of Tripoli, Libya
E-mail: jesalah@yahoo.com

الملخص

تم استخدام مخلفات البوليستايرين المتمدد الخفيفة الوزن جزئيا (أو كليا) كبديل للركام الخشن المستعمل في إنتاج مواد البناء (الخرسانة). حيث كانت نسبة الاستبدال تعادل 25، 50، 75 و 100% من حجم الركام الخشن.

تهدف هذه الدراسة للاستفادة من هذه المخلفات ودراسة أداء هذا المركب المحتوي على البوليستايرين المتمدد في غياب أي نوع من محسنات الروابط أو أى إضافات أخرى. لقد تمت دراسة تأثير إضافة هذه المخلفات على بعض خواص المادة المنتجة مثل مقاومة الانحناء وامتصاص الماء والانكماش.

أظهرت النتائج العملية أن انخفاض الكثافة بمقدار 12% نتيجة استبدال 25% من الركام الخشن بالبوليستايرين المتمدد أحدث انخفاض في مقاومة الانحناء بمعدل 25.3٪ وأن هذه النسبة من الانخفاض تعتمد على مستوى استبدال حبيبات البوليستايرين. كما أظهرت نتائج اختبار امتصاص الماء أن المواد المنتجة ذات المقاومة المنخفضة لها امتصاص أعلى مقارنة بالمواد ذات المقاومة الأعلى أى بمعنى أن نسبة الامتصاص تزداد كلما زادت النسبة الحجمية للبوليستايرين المتمدد. كما وجد أن نسبة الماء إلي الاسمنت المستخدم لإنتاج هذه المادة المركبة هي أقل من تلك المستخدمة لإنتاج الخرسانة العادية. أما التغير الطولي (الانكماش) فهو أعلى في المادة المنتجة مما هو في المواد الخرسانية المعروفة.

ABSTRACT

The expanded polystyrene (EPS) waste is used as lightweight aggregate in order to replace the coarse aggregate which is commonly used in building materials such as concrete. The replacement levels used are 15, 30, 45, 60, and 75 percent. The aim of this work is to study the effect of varying the amounts of expanded polystyrene on the flexure strength, water absorption and shrinkage of the produced material.

Experimental results showed that the flexure strength decreased with an increase in the percentage of expanded polystyrene. The samples that did not contain EPS exhibited brittle failure, whereas, gradual failure was observed when EPS is involved. Moreover, the lower strength produced material showed a higher water absorption values and a higher negative strain (shrinkage) compared to higher strength one. The water to cement ratio of EPS aggregate material is found to be slightly lower than that of conventional building material.

KEYWORDS: Building Materials; Concrete; Expanded Polystyrene; Flexural Strength; Light Weight Aggregate; Polymer; Shrinkage; Water Absorption.

INTRODUCTION

The most important building (construction) material is the concrete. Based on unit weight, concrete can be classified into three categories, the first is heavy weight concrete which is used for radiation shielding. This concrete is produced from high density aggregates. The second type is containing natural sand and gravel or crushed-rock aggregate which is called normal-weight concrete, and is the most commonly used concrete for Structural purposes. The third type is lightweight concrete.

Lightweight concrete (LWC) is a material of substantially lower bulk density than that made from gravel or crushed stone. The lower bulk density is produced by using lightweight aggregates that may be naturally occurring or processed materials. There are many types of aggregates available that are classed as lightweight, and they may be used in low-density, structural materials.

Low density concretes are especially light in mass, seldom exceeding 800 kg/m^3 (50 lb/ft^3), and are employed chiefly for insulation purposes. Thermal insulation values are high, but compressive strengths are low, ranging from approximately0.7 to 7.0 MPa (100 to 1000 psi).Vermiculite and perlite are the most common aggregates used in this type of concrete. [1]

The most common aggregates used in this type of building material are expanded slags, sintering-grade expanded shale, clay, or fly ash, and rotary-kiln expanded shale, clay, or slate. Expanded slag is produced either by rapidly agitating molten blast-furnace slag in a machine with a controlled amount of water, or by treating the molten slag with a controlled amount of water forced into the mass in jets under high pressure. In both processes, the material is subsequently cooled and crushed [1]. Artificial aggregate is produced by certain manufacturing processes; Slag, glass, expanded polystyrene, etc, are some examples of artificial aggregates.

Expanded Polystyrene (EPS) is a thermoplastic, closed cell, Light- weight, rigid foam plastic. Expanded Polystyrene comes as small beads of resin. The beads are impregnated with the naturally occurring gas, pentane. The beads are then heated in a pre-expander; with the combination of this heat, and the rapid release of the gas, the bead is expanded to almost 50 times its original size. EPS is a scientifically innovative material that, since its introduction in Germany in 1930, has captured an ever growing range of accepted applications throughout the world. Expanded polystyrene (EPS) lightweight concrete is gradually used in various applications in the construction industry due to its lightweight, excellent heat preservation and sound insulation. It can be used as sub materials for pavements and rail way track beds and also in floating marine structures. [1]. EPS is a truly proven versatile, inert material which exhibits the following unbeatable qualities such as, a highly efficient thermal insulation value, excellent shock absorption, a very high flexural strength to weight ratio, an economically viable material, compatible with the environment, a proven dimensional stability, moisture resistant, compatible with a very wide range of other products, non toxic and non irritant [2]. Finally, the addition of EPS in place of normal aggregate not only reduce the weight of construction material but could also reduce the permeability and increase the resistance to chemical attack, because of the closed cellular and inert nature of these aggregates. [1]

Flexural strength, also known as modulus of rupture (MOR), bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a rod specimen having either a circular or rectangular cross section is bent until fracture using a flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. Flexure testing is often done on relatively flexible materials such as polymers, wood and composites. There are two standard Flexure Test methods known as, 3-Point Flexure Test and 4-Point Flexure Test.

In the 3-point test, a specimen with round, rectangular or flat cross-section is placed on two parallel supporting pins. The loading force is applied in the middle by means of loading pin, while, in the 4-point test, the loading force is applied by means of two loading pins with a distance between them equal to half of the distance between the supporting pins as shown in Figure (1).

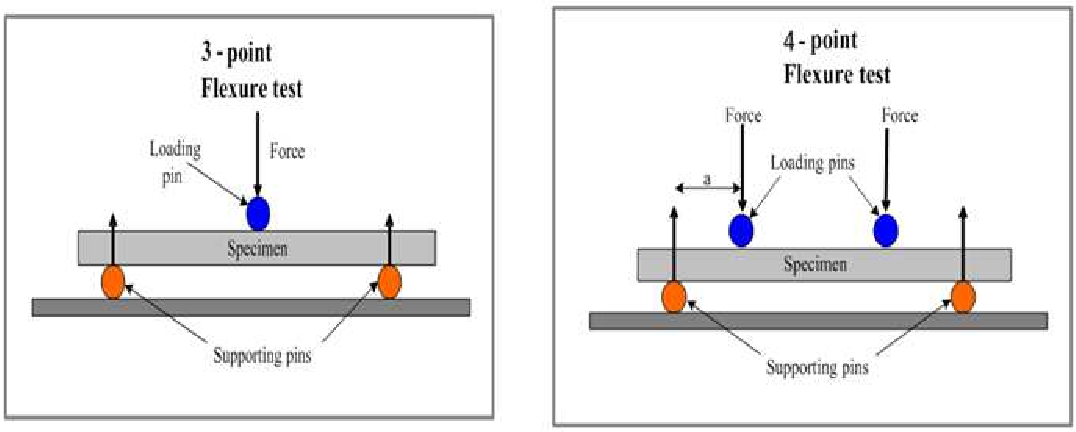

Figure 1: flexural test

Collins and Ravindrajah studied the effect of incorporating expanded polystyrene beads in concrete on the temperature development in an insulated thick concrete section. The results showed that as the polystyrene beads content was increased, the recorded peak concrete temperature increased [3]. The engineering properties, such as compressive strength, modulus of elasticity, drying shrinkage and creep of polystyrene aggregate concrete varying in density have been investigated by Ben sabaa and Ravindraraja [4]. Their results showed that the drying shrinkage and the creep of polystyrene aggregate concrete increased, whereas the compressive strength and the modulus of elasticity decreased with decreasing the density of concrete.

Another work of Ravinrarajah and L.Subhan [5] presents an experimental investigation of the effects of incorporating varying amounts of expanded polystyrene beads on the engineering properties of high strength concrete. They found that a density reduction of 8.35% caused tensile strength and modulus of elasticity to reduce by 39% and 15% respectively

Babu, et-al [6] studied the effect of polystyrene aggregate size on strength migration characteristics of light weight Concrete. This study covers the use of expanded polystyrene (EPS) and un-expanded polystyrene (UEPS) beads as lightweight aggregate in concrete, and proved through this study that for comparable aggregate size and concrete density concrete with UEPS aggregate exhibited 70% higher compressive strength than EPS aggregate.

A.Tuck and Ravindrarajah [7] studied the properties of hardened concrete containing chemically treated expanded polystyrene Beads. The results showed that the strength stiffness and chemical resistance of polystyrene aggregate concrete of a constant density were affected by the water to cement ratio.

In this work, the lightweight building material (concrete) is produced by partially replacing the normal weight coarse aggregate particles with expanded polystyrene granules. The effect of this replacement on the flexural strength, water absorption and shrinkage of the produced building material was investigated.

EXPERIMENTAL WORK

Materials

Ordinary Portland cement conforming to Libyan standard number (49/2001) was used as received, as a binder material in the concrete mixtures. Normal sand was used as fine aggregate in the concrete mixes. Crushed stone, having a maximum size of 5mm was used as coarse aggregate. Fine materials were reducing by sieving process. Commercially expanded polystyrene from packaging material waste was used as a replacement or exchange aggregate. EPS aggregate was in granules irregular shape, obtained by grinding the waste molded expanded polystyrene. Natural water conforming to Libyan standard number (249/88) was used.

A digital flexure testing machine was used for measuring the flexural strength. An electronic balance of 45 Kg as maximum load, capable of measuring to three decimal places was used for weighing cement, sand and coarse aggregate. A cube mold of 150mm and beam mold of 100*100*500mm were used for forming the specimen. A titling drum mixer of conical shape was used for the mixing step. Scoops, spatulas, trowels and float were used for specimen preparation.

The equipments that are needed for each mix such as pans, moulds, bowels, sample containers, mixer machine, were cleaned by different ways, such as rinsing with water, using wet & dry cotton cloths, brushes, and/or spatulas as in case of cleaning the steel moulds. The coarse aggregate and sand were mixed. The solid constituents (cement, sand) were mixed for a minute or until the color of mixture changed into homogenous mixture in titling drum mixer. Coarse aggregate were then added and mixing continued for another two minutes. The required amount of water was gradually added and mixing continued for one more minute.

For producing the required amounts of EPS fresh concrete mixtures, the same above procedure was repeated. Where, the expanded polystyrene aggregates were gradually added while the mixing process in progress, and mixing continued until a uniform mixture was obtained.

The polystyrene aggregate building material was produced by partially replacing the coarse aggregate in the normal weight concrete mixture with equal volume of grinded expanded polystyrene granules. The coarse aggregate replacements levels were, 0, 15, 30, 45, 60 and 75% of EPS.

The water to cement ratio was kept constant for all mixtures at 0.50 based on a common weight ratio mixing widely used as 1 : 2 : 3 of cement to sand to coarse aggregate, respectively.

RESULTS AND DISCUSSION

The effect of EPS on the Flexural strength of concrete

As a result of the loading, the specimen bends, causing formation of its convex side and compression stress in the concave side. The maximum stress and corresponding maximum strain are calculated for every load value. The results are then plotted in the stress-strain diagram.

Flexural Strength is calculated by the formula,

$\sigma = 3LF / (2bd^2)$, for the 3-point test of rectangular specimen, and the formula,

$\sigma = 3Fa / (bd^2)$ for the 4-point test of rectangular specimen.

Where, **L** is the length of the support span, **F** is the total force applied to the specimen by two loading pins, **b** is the specimen width, **d** is the specimen thickness, and **a** is the distance between the supporting and loading pins [10].

Figures (2-4), Show the effect of replacement level (vol. %) of EPS on the flexural strength. It is found that the flexural strength decreased as the volume percentage of EPS is increased. The 3-point test gave higher values of flexural strength than the values obtained from 4-point test. It was observed that the crack growth upwards of specimens containing EPS aggregates was inhibited, may be due to strain gradient in the specimens, and the propagation of a crack is blocked by less stressed material nearer the neutral axis.

Thus the energy available is below that necessary for the formation of new crack surface. This phenomenon could be due to the ability of EPS aggregates to absorb the stresses that may cause the cracks propagation and resulting in better stress distribution.

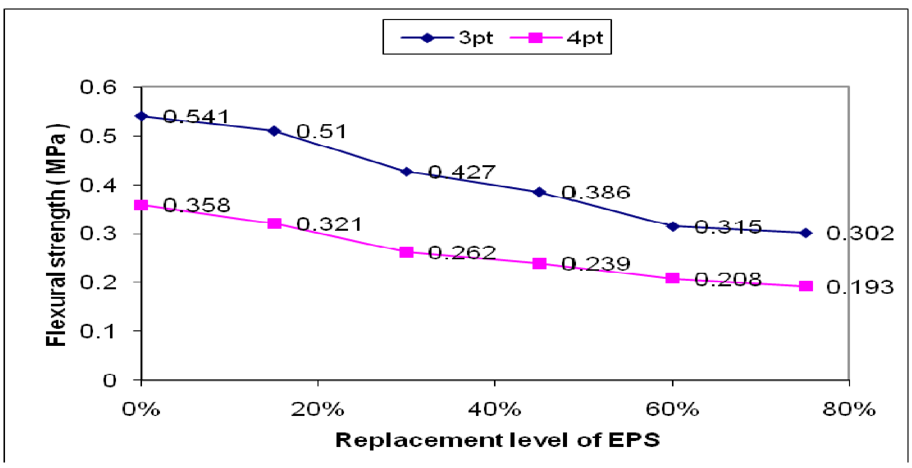

Figure 2: Flexural strength at different EPS replacement levels.

Moreover, the failure mode of EPS aggregates concrete specimens did not exhibit the typical brittle failure normally observed in normal concrete (0% EPS) as can be seen in the Figure (3). The failure observed was more gradual (compressible) and the specimens did not separate in two, because the fracture toughness was improved at those specimens as seen in Figure (4). This may provide an advantage of EPS concrete over the conventional concrete. Furthermore, the failure occurred around the EPS aggregates rather than through the aggregates as associated with the conventional lightweight aggregates. Brittle failure was observed in normal concrete (0% EPS) and no cracks were observed in 100% EPS specimens as shown in Figure (4).

Figure 3: Crack formation in a 50% EPS Specimen

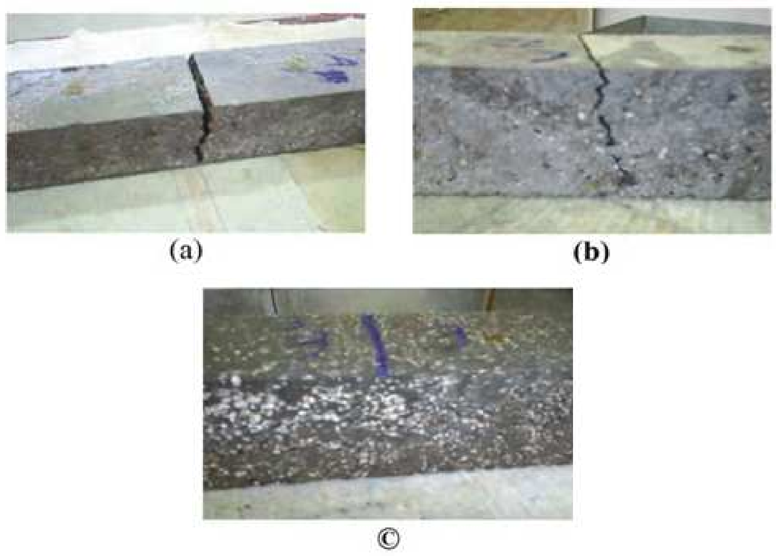

Figure 4: Failure mode in flexural test, (a) 0 %EPS, (b) 50% EPS, (c) 100% EPS

The effect of EPS on the Water Absorption of concrete

Most normal - weight aggregates (fine and course) have an absorption capacity in the range of 1 to 2%. Abnormally high absorption capacities indicate high - porosity aggregates, which may have potential durability problems. Conventional lightweight aggregates generally have very high absorption capacities. The absorption characteristics indirectly represent the porosity, through an understanding of the permeable pore volume and its connectivity. In the present study, the absorption test was carried out according to ASTM C 642-97. The results are shown in Figure (5), the absorption percentage values calculated from the following equation:

Absorption % = (B - A) / A x100

Where, B is the mass of saturated specimen, and A is the mass of oven dried specimen

The results indicated that as EPS aggregates content increased the water absorption percent increased, it was also observed that the EPS concrete absorbed a lot of water, which drained off immediately after removal from water, this was un-expected, because EPS granules are non-absorbent, hydrophobic, closed cellular structure, and there is no capillary action. Visual examination of the concrete slices indicated that the EPS aggregates were shrunk and changed to solid granules during drying process, and their sizes reduced due to expanded of the air content making an empty place or a gap around the reminder UEPS aggregates as shown in Figure (6a&b).

As the volume percentage of EPS content increased, the number of pores that were filled with water increased and hence the absorption became higher.

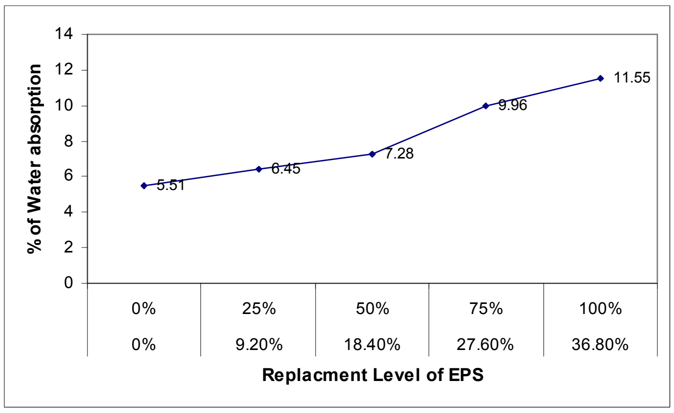

Figure 5: Effect of EPS aggregates on the water absorption (100 mm cube, 30 days)

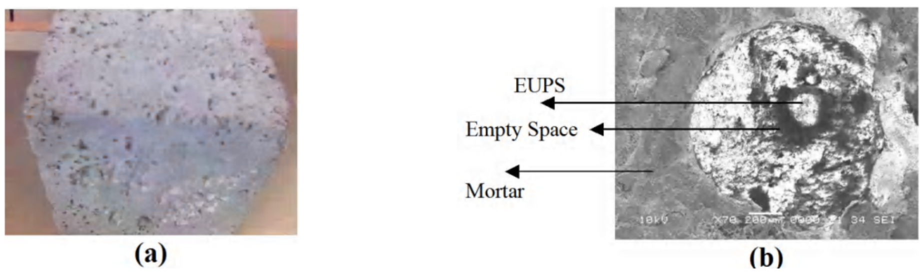

Figure 6: (a) Effect of drying process (b) An SEM image showing shrinkage of EPS granule

The effect of EPS on the change in length (shrinkage) of concrete

Two rectangular beam of 200 mm gage length used to determine the changes in length of the concrete after 28 - days from water cured, then stored in an uncontrolled laboratory environment, having the mean temperature and humidity of 21°C and 50% R.H. respectively. Laboratory, these changes are monitored by calculating longitudinal strain, from the following equation

$$Straing = \frac{Extension\ (mm)}{Gage\ length\ (mm)}$$

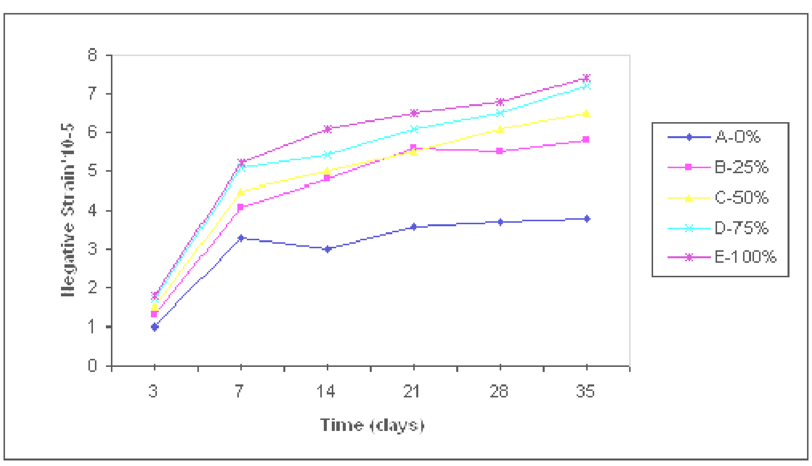

Figure 7: Effect of EPS aggregate on the change in length of concrete

Figure (7) shows the effect of EPS aggregates on the behavior of the specimens when exposed to dry at uncontrolled environment. It was found that, as the volume percentage of EPS aggregates increased the negative strain of the specimens increased also. This increase could be due to the low stiffness and compressibility of polystyrene aggregate particles which provide very little restraint to the shrinkage of paste, and to the reduction in the amount of rigid coarse aggregate particles, since; the shrinkage is a paste property. This caused the shrinkage of EPS aggregate concrete to increase over that for the conventional concrete.

CONCLUSIONS

Partial replacement of normal weight coarse aggregate with polystyrene aggregate has changed the flexure strength of the concrete. The flexure strength decreased as the amount of EPS aggregate increased.

The flexure failure mode of the concrete specimens containing EPS aggregates showed more gradual (more elastic) and the conventional concrete showed the typical brittle failure.

All the EPS concretes showed a higher water absorption percentage than the conventional concrete (namely) the absorption increases with increasing EPS volume percent. Since this filler is hydrophobic and it has a closed cellular structure, this result was due to shrinkage of EPS aggregates during the test only. The change in length (shrinkage) due to loss of water of all EPS concretes was higher than that for normal weight concrete, because EPS aggregate possesses the property of high compressibility, which may provide a little restraint to volume changes of mortar due to the changes in the moisture content.

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Abbreviations	Description	Abbreviations	Description
EPS	Expanded Polystyrene	NWC	Normal- weight concrete
PAC	Polystyrene Aggregate Concrete	LWC	Lightweight concrete
w/c	Water to Cement ratio	ASTM	American Society for Testing of Material
hcp	Hardened Cement Paste	SEM	Scanning Electron Microscope
EPF	Expanded Polystyrene Foam		