THE INFLUENCE OF RECYCLED EXPANDED POLYSTYRENE (EPS) ON CONCRETE: I- INFLUENCE ON DENSITY AND COMPRESSIVE STRENGTH

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الملخص

مخلفات البوليستايرين المتمدد ذات الشكل الحبيبي المستخدم في تغليف وحفظ الأجهزة الكهربائية والالكترونية، تم إعادة استخدامها كركام خفيف الوزن من اجل إنتاج خرسانة خفيفة الوزن ذات كثافة متفاوتة. مركب خرسانة البوليستايرين المتمدد الخفيفة الوزن تم إنتاجه باستبدال الركام الخشن جزئيا أو كليا بحجم مساوي من ركام البوليستايرين المتمدد وكانت نسبة الاستبدال هي 25، 50، 75 و 100% من حجم الركام الخشن أي ما يعادل 9.20، 18.40، 27.60، و 36.80% من الحجم الكلي.

الهدف المباشر لهذه الدراسة هو تقويم ومتابعة إنجاز وتطوير مركب الخرسانة المحتوي على البوليستايرين المتمدد في عدم وجود أي نوع من محسنات الروابط أو أي إضافات أخرى على بعض خواص الخرسانة مثل مقاومة الضغط والكثافة.

أظهرت النتائج المعملية أن انخفاض الكثافة بمقدار 12% نتيجة استبدال 25% من الركام الخشن بالبوليستايرين المتمدد أحدث انخفاض في مقاومة الضغط بمعدل 45%. هذه النسبة من الانخفاض تعتمد على مستوى استبدال حبيبات البوليستايرين.

ABSTRACT

Recycled expanded polystyrene waste in a granular form is used as lightweight aggregate in order to produce lightweight structural concrete. Lightweight EPS concrete composites were produced by replacing the coarse aggregate, either partially or fully with equal volume of EPS aggregates. The coarse aggregate replacements levels used were 25, 50, 75, and 100%, which corresponded to (9.20, 18.40, 27.60, and 36.8%) from total volume. The present investigation is directed towards the development and performance evaluation of the concrete composites containing EPS aggregates, without addition of either bonding additives, or superplasticizers on some concrete properties such as compressive strength, density.

Experimental results showed that a density reduction of 12% caused a decrease in compressive strength by 45% at a replacement level of 25% EPS. However, the reduction percentage strongly depends upon the replacement level of EPS granules. The water to cement ratio of EPS aggregate concrete is found to be slightly lower than that of conventional concrete.

KEYWORDS: Concrete; Light Weight Aggregate; Expanded Polystyrene (EPS); Compressive Strength

INTRODUCTION

The aggregates are added to the cement paste for producing concrete. They occupy about 70-80% of the total concrete volume. The aggregates can be thought of as being inert fillers, or modifiers of concrete properties. They can be obtained from natural sources such as common rocks, or specifically manufactured for use in concrete. They are classified as heavyweight, normal-weight, and lightweight aggregates. Lightweight aggregates are used to produce lower density concrete. They have advantages such as, reducing the weight of the structure and also having better thermal insulation compared to normal weight concrete. However, the use of porous low specific gravity results in lowering of the concrete strength. The quality and properties of different aggregates vary considerably, and produce different strength/density relationships. Therefore, the properties of concrete depend on the aggregate type and source, as well as, on the properties of the other constituents of the concrete [1].

One of the challenges today is to produce low density, low thermal conductivity and high moisture-resistant concrete. However, this can be done by replacing the aggregates (fine or coarse), with other materials of different properties such as expanded polystyrene (EPS). Polystyrene (PS) and EPS (commonly known as plastic foam) are made from non-renewable petroleum based chemicals. PS is light, hygienic and commonly used to pack food, drinks and deformable goods. Usually, EPS products are 98% air and only 2% PS. EPS is a closed cell, lightweight and resilient, foamed plastic composed of hydrogen and carbon atoms. The mechanical strength of EPS varies with its density. The most important mechanical property of EPS insulation and building products is its resistance to compressive stresses, which increase as the density becomes higher [2].

Incorporating expanded polystyrene in the form of either beads or granules in a concrete matrix can produce lightweight polystyrene aggregate concrete (PAC) of various densities, which is a new type of lightweight concrete.

Compressive strength is widely considered to be the most important property of concrete. This is because in most structural applications concrete is employed primarily to resist compressive stresses as well as compressive strength is so much greater than tensile strength.

Lightweight concretes can be divided into structural lightweight concretes and ultra-lightweight concretes used for nonstructural purposes. Structural lightweight concrete has density between 1440 - 1920 kg/m^3 and a 28 - days compressive strength in excess of 17 MPa [3]. Lightweight concrete is used principally to reduce the dead - load of structure and lower the cost of foundations. The light weight of the aggregates used for this type of concrete is a result of the cellular and porous structure of the aggregates.

Lightweight aggregates can be either natural or synthetic materials. The common feature of lightweight aggregates is their high internal porosity, which is the prime reason for their low bulk specific gravity. Lightweight aggregates have densities significantly lower than normal - weight aggregates, ranging from 560 to 1120 kg/m^3. The possibility of using solid wastes as aggregate in concrete serves as one promising solution to the escalating solid - waste problem.

When considering a waste material as a concrete aggregate, three major areas are relevant: (1) economy, (2) compatibility with other materials, and (3) concrete properties. The successful use of solid waste in concrete will depend on anticipating potential problems and the ensuing properties of the concrete, and developing uses that comply with these restraints [3-5].

Although the w/c ratio is the most important factor affecting compressive strength, the properties of aggregate cannot be ignored, particularly in the case of tensile and fracture properties. For normal – strength concretes, the aggregate parameters that are most important are the shape, texture, and maximum size of the aggregate. The aggregate strength itself is of less importance, since aggregates are generally much stronger than the cement paste. In the case of lightweight aggregates or high – strength concrete, however, aggregate strength can play a much greater role due to the relatively high strength of the cement paste constituent of these concretes relative to the strength of the aggregates. The surface texture affects both the bond and the stress at which microcracking begins [6,7].

When considering the effect of aggregates on workability, two factors are important: the amount of the aggregate and the relative proportions of fine to coarse aggregate. For a constant water to cement ratio, an increase in the aggregate to cement ratio will decrease the workability. The shape and texture of aggregate particles can also affect the workability.

As mentioned earlier, aggregate particles can be from a natural material or from a synthetic material such as expanded polystyrene beads. EPS has been used as a filler over metal roof decks, in partitions and in panel walls [8,9].

Polystyrene is an odorless, tasteless and thermoplastic polymeric material. Pure polystyrene is brittle and has the following structure.

Expanded polystyrene (EPS) is a generic term for polystyrene and styrene copolymers that are expanded into a variety of useful products. Expanded polystyrene is stable low density foam and consists of discrete air voids in polymer matrix. The EPS beads can be easily incorporated in mortar or concrete to produce lightweight concrete with a wide range of density [10].

At a high - strength concrete the reduction in the density caused compressive strength, tensile strength, and modulus of elasticity to decrease. Drying shrinkage was marginally increased and the concrete showed considerable ductility [11]. In this work, polystyrene aggregate concrete was produced by partially replacing coarse aggregate in the normal weight concrete mixture with an equal volume of ground recycled expanded polystyrene waste from the packaging industry of an average density of about 16 kg/m^3. The effect of exchanging the normal (rock - type) aggregates with polymer - type aggregates (recycled EPS) of various grain sizes on compressive strength, and density.

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. Dolomite crushed stone, having a maximum size of 5 mm was used as coarse aggregate (C.A). Fine materials were reduced 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. The maximum size for polystyrene aggregate was about 7.0mm with density of about 16 kg/m^3. The microstructure of the used EPS is shown in Figure (1). Natural water conforming to Libyan standard number (294/88) was used. Mould oil EL82-7341 was used as a lubricant material.

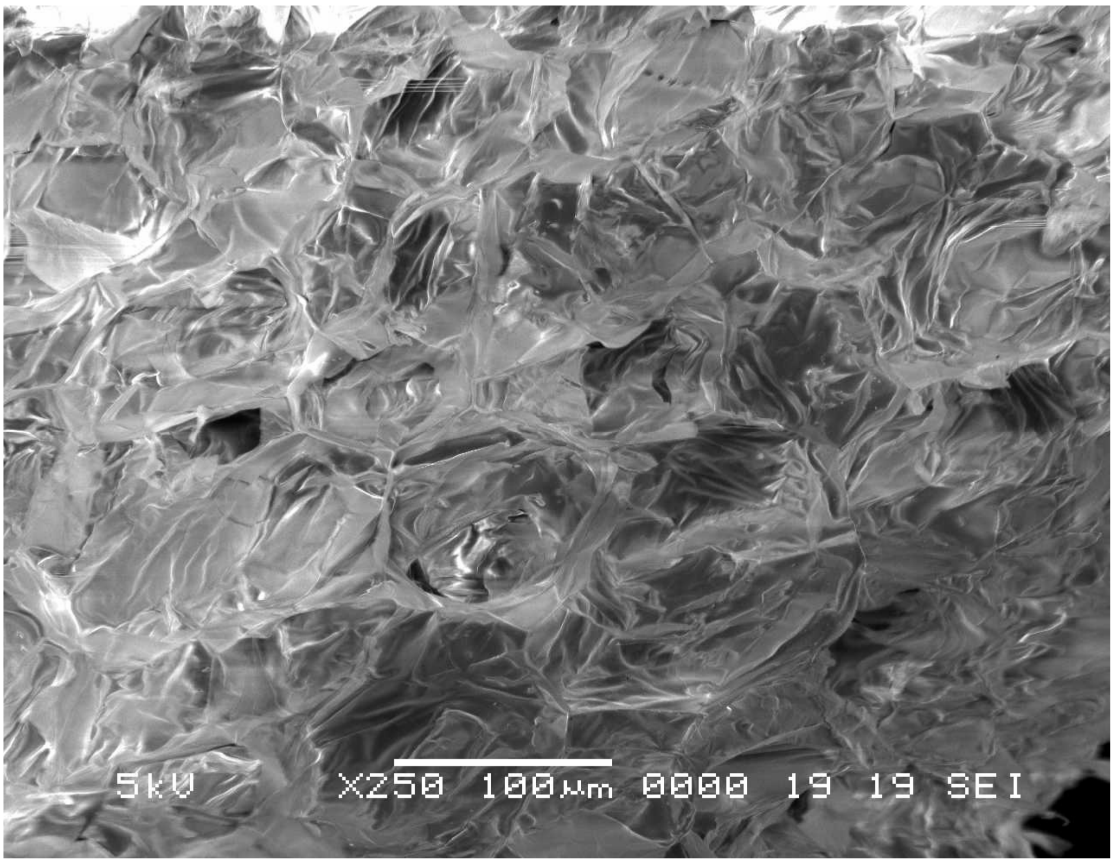


Figure 1: SEM image of the microstructure of EPS used in the present work

A digital compressive was used for measuring compressive strength, with load of 3.0 kN/Sec., for 100 mm cube. An electronic balance of 30 kg as maximum load, capable of measuring to three decimal places was used for weighting cement, sand and coarse aggregate. Measuring cylinders made from glass and plastic material of a different capacity were used to measure the volume of EPS aggregate. Metallic moulds made from steel of was used as 100 mm Cube mould (EL 34-4520). A titling drum mixer of a conical shape was used. Riffle boxes, EL 22-3000, and EL22-3070 were used for homogenization of the sand and aggregate during the preparation process for the mixing. A steel rod (EL 34-0130) of 16 mm diameter with a rounded shape at one end was used to obtain good compaction.

9- Bulk density measures, EL 42-1995, capacity of 3 liter, and EL 42-2000, capacity of 7 liter were utilized. Scoops, Spatulas, Trowels, and Float of different sizes were used for specimen's preparation and surface finishing. Sample containers, Bowls, and Buckets of different capacities were used. Woven wire mesh test sieves series with octagon sieve shaker, EL80-0380 were used. Sieve brushers, EL 79-7200, EL 79-7210, and EL 79-7250 were utilized. Drying oven model 'Memmert' with a temperature range from 40 to 200◦C was used. Finally, the structure of the concrete was investigated using an image analysis, namely, Scanning Electron Microscopy and digital photo camera. No chemical coating for EPS was used; also no super-plasticizer or any bonding additives were added to the concrete mixtures.

Mixing Procedure

The coarse aggregate and sand were homogenized by using Riffle Boxes. The constituents of the concretes were weighed at the individual pans (cement, coarse aggregate, sand and mixing water). 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 aggregates were then added and mixing continued for two more 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 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 concrete was produced by partially replacing coarse aggregate in the normal weight concrete mixture with equal volume of ground expanded polystyrene granules. The coarse aggregate replacements levels were, 0, 25, 50, 75 and 100% which corresponded to 0, 9.20, 18.40, 27.60, and 36.8% from the total volume. The water to cement ratio was kept constant for all mixtures at 0.5. The incorporation of EPS granules with the mortar is shown in Figure (2).

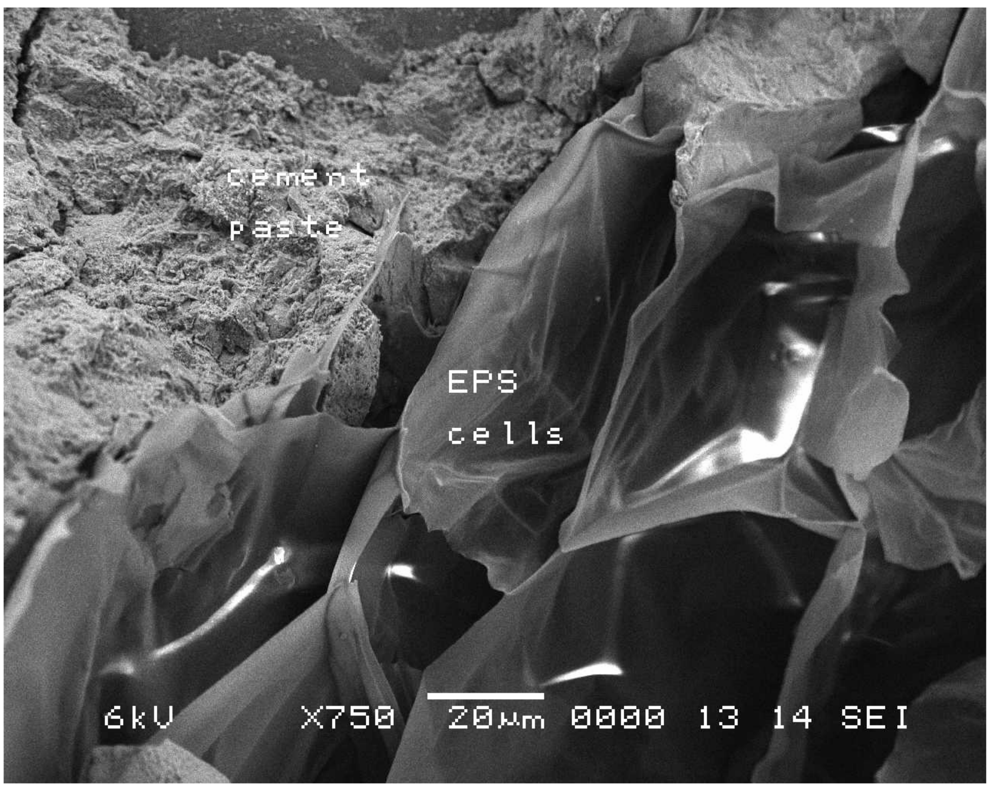


Figure 2: Incorporation of EPS granules with the mortar

From each concrete mixture; eight cubes of 100×100×100 mm^3 were prepared in standard steel moulds. Before casting, the moulds were cleaned by spatulas to remove any stuck materials remaining from other experiments, then cleaned with a dry cotton cloth, a small amount of lubricant was then applied to the clean surfaces, so, that specimens can be removed easily. Concrete mix was then poured in to the mould over three installments; the mixture was compacted using a steel rod after each addition, finally, a float used for the finishing of the casting surface. Care was taken to ensure that the moulds did not deform during preparation of concrete specimens by ensuring that the dimensions of the moulds are to be maintained. The cubes were used to determine the compressive strength, density and absorption percentage. The beams were used to determine the shrinkage strain and flexural strength.

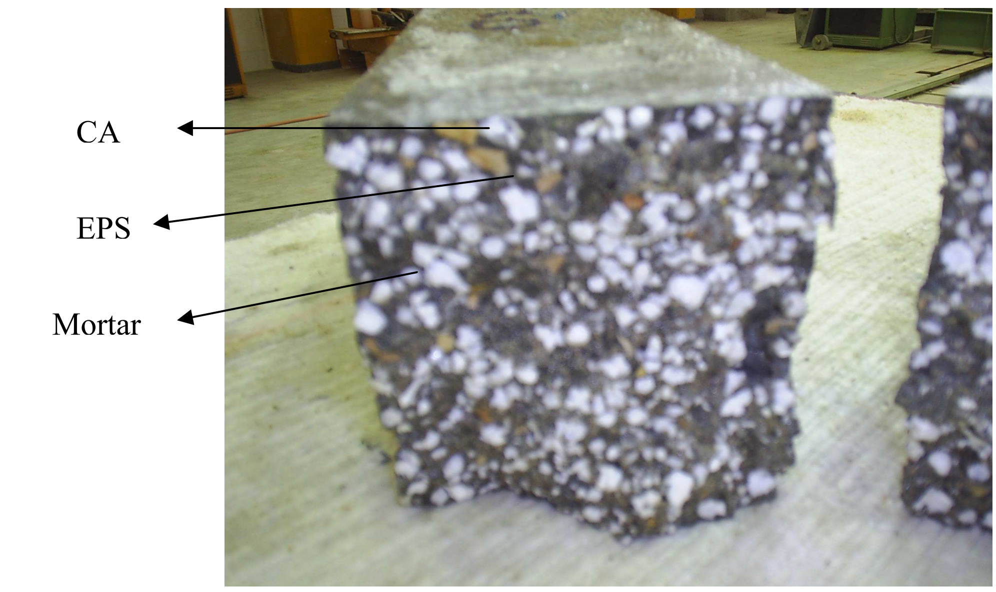
The specimens were removed carefully from their moulds after 24 hours from casting and then weighted in order to calculate the wet density. The castings were then placed in a water bath at 20 ± 1°C of which the temperature and water level were monitored daily. The water - cured specimens were tested for their compressive strength at the age of 14 and 28 days. The tests were carried out at ambient temperature. Before each test, the specimens were removed from the water – bath, left to air dry at ambient temperature for about fifteen minutes, and were then weighed to calculate their density after curing and then, tested. In the compression test, the cubes tested at the right angles to the direction in which they were cast.

RESULTS AND DISCUSSION

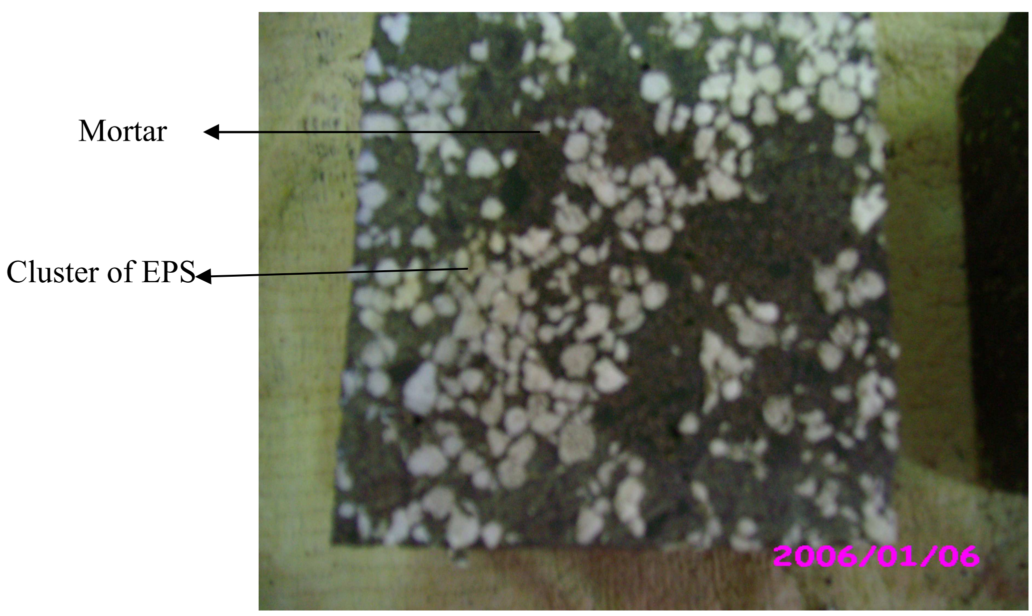
By incorporating the EPS granules from waste industry at different volume percentages in concrete, mortar, or cement paste, a wide range of concrete densities can be achieved or polystyrene aggregate concrete can be produced. Polystyrene aggregate concrete was produced by systematically replacing the coarse aggregate with EPS granules, in order to study the effect of the exchange on some of the concrete properties such as compressive strength. The work encountered some difficulties during the preparations, which had to be overcome in order to obtain represtentive samples that can be investigated properly, some of these were;

i- Determining the optimum value for water to cement ratio. Initially, 0.8 value was selected for 0% EPS mixture based on accepted previous practices. However, the mixture that was obtained had high fluidity. In order to overcome that problem, the value of w/c ratio was reduced to 0.6, and the coarse aggregate was sieved in order to minimize the fine materials, which was expected to lower water retention tendency of the mixture. It seemed to be a good ratio for 0% EPS mix, as it yielded good workability. But after exchanging coarse aggregate with EPS granules and during the preparation of the mixes, it was noted that bleeding started (formation of a layer of water at the upper surface) during surface finishing of the specimens which may result in incomplete hydration as well as formation of cracks due to evaporation. Considering the fact that EPS aggregate tend to resist water absorption. Therefore, w/c ratio was reduced to 0.5 which satisfied the properties that were needed in the fresh concrete such as, good workability, good hand compaction, and with no bleeding.

ii- Ensuring homogeneity of EPS aggregate with the other constituents during the mixing process. Initially, a titling - pan type mixer was used because the large quantities of solid materials have to be employed. Although, EPS aggregates were added gradually, it was found that EPS aggregates tended to scatter and stick to the inner pan surfaces. It was found that this type of mixer was unsuitable because of its limited titling range, shallow mixing pan depth as well as large feeding mouth. This resulted in an increased air flow which may have blown the light hydrophobic aggregates off the surface of the mix instead of incorporating them into it. In the second try, the titling - pan type mixer was replaced by conical shape gradually titling-drum mixer. EPS aggregates were added while the mixing process continued. Initially, it was found that the aggregates adhered to the inside surfaces of the mixer due to their nature. However, due to the gradual sloping conical shape of the pan, and because of relatively high depth of the mixer plus the type of motion of the mixer and minimized air flow, EPS aggregates were assimilated back from the surfaces and mixed with the other components as shown in the Figure (3a), except when coarse aggregate was completely replaced with EPS aggregate as seen in Figure (3b). This behavior could be due to presence of specific interactions between the coarse aggregates and EPS granules or may be attributed to the amount of water absorbed by the coarse aggregates.



(a) D-mix



(b) E-mix

Figure 3: A comparison in homogeneity between two samples (a) D-sample (b) E-sample

iii- Ensuring good specimens compaction. In the laboratory, the facilities for compaction were limited; it was either by using a vibrating table or by using tamping rod (hand compaction). Vibrating table is the common method used for many types of concretes. Initially, vibrating table was used to achieve a good compaction. But, it was found that the vibration resulted in separation of EPS from the concrete mixture, and collected in separated layers, as shown in the Figure (4). This is may be due to the absence of the bonding enhancing additives and nature of EPS. In order to avoid the separation and to get a good compaction, vibrating table was replaced by steel rod of rounded shape at one end.

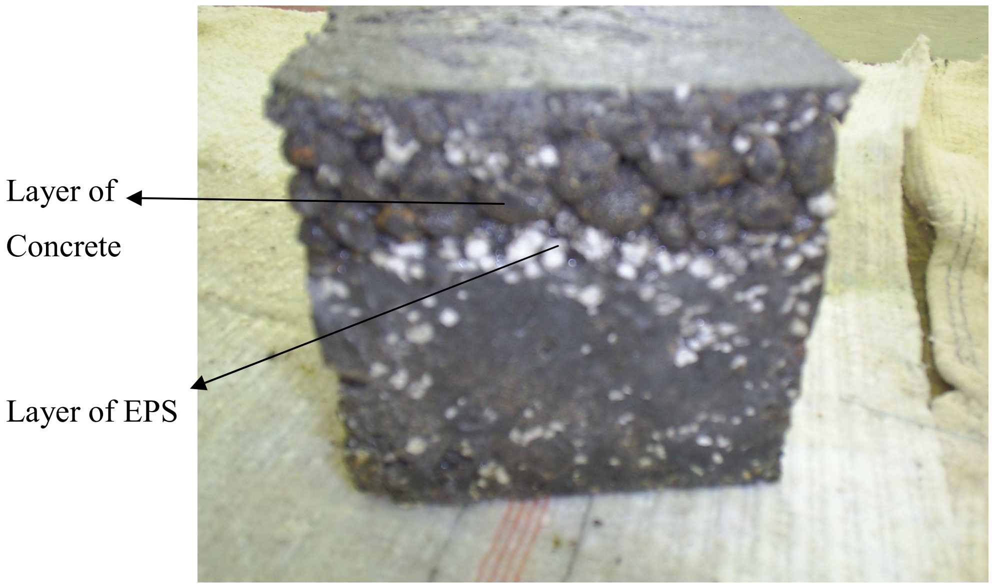


Figure 4: Segregation phenomenon due to the use of Vibrating Table

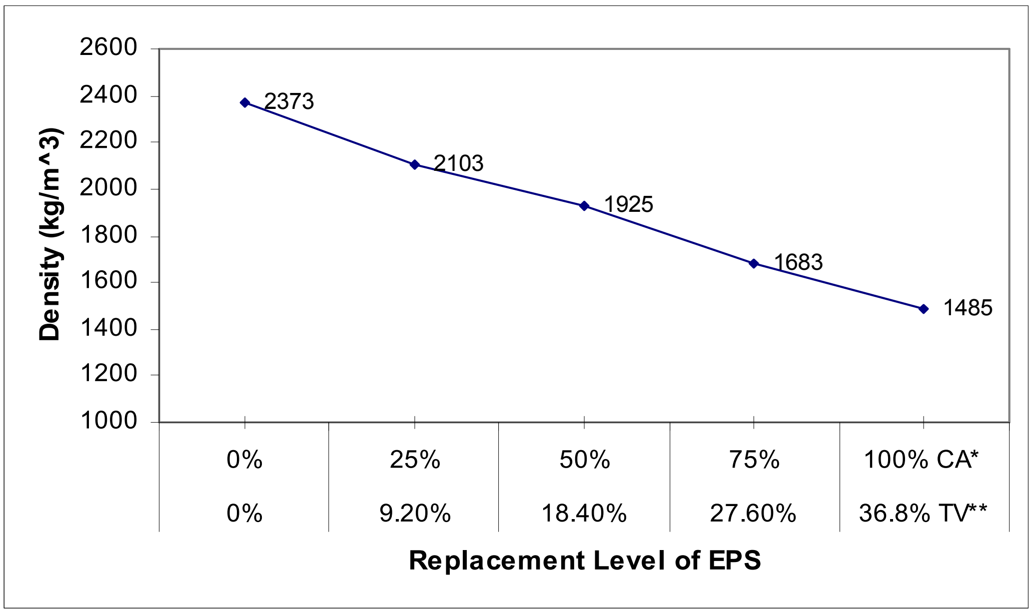
vi- Surface finishing of EPS aggregate concrete. The fresh polystyrene concrete mixes were lumpy and elastic and hence caused some difficulties during the finishing process, and needed a very good hand experience in order to minimize the surface roughness. In order to overcome this problem, an optimized value of w/c ratio must be estimated.

The effect of EPS on density of concrete

Density is one of the important parameters which can control many physical properties in lightweight concrete and it is mainly controlled by the amount and density of lightweight aggregate, by replacing normal weight aggregate by EPS aggregate, the density of the concrete will be varied. Where, the density of the concrete was controlled by varying the EPS volume in the mixes. The obtained results are presented in Table (1) and Figure (5). The wet density (density measured after 24 hours molded) of concrete decreased with the increase in the volume percentage of EPS aggregates. When 9.20% of the total volume of coarse aggregate replaced with EPS granules, which corresponding to 25% replacement level, the wet density was reduced from 2335 to 2056 kg/m^3. This corresponded to a reduction of 12% in density, as a result of the nature of EPS granules (contain about 98% air), or because of the entrapped air content of concrete mixes, moreover, it was apparent that full compaction was difficult to achieve with the expanded polystyrene mixes. Also the differences between the density of fresh concrete and density of concretes after 14 days curing were small in the EPS concretes, probably due to the presence of discrete non-absorbent polystyrene granules.

Table 1: Density measurements concretes (100 mm cube)

Mix Designation	Wet Density (kg/m^3)	Density (kg/m^3) /14 days
A	2335	2373
B	2056	2103
C	1883	1925
D	1648	1683
E	1441	1485



CA*; *from the C.A volume* ***TV*****; *from the total volume*

Figure 5: Effect of EPS aggregates on the density of concrete (100 mm cube, 14 days)

The effect of EPS on the compressive strength of concrete

The strength of concrete is mainly influenced by the strength h of the aggregate used. The development of high - strength concretes is possible only when the aggregates having enough strength. Figure (6) shows the effect of EPS aggregates on the compressive strength of concrete for two different curing durations 14 days and 28 days. It was found that as the volume percentage of EPS aggregates increased, the compressive strength of the concrete mixes decreased as shown in Figure (6). This variation of compressive strength is mainly due to the difference in the strength of the aggregates (C.A and EPS), as EPS aggregates have very low compressive strength as well as the variation in density of concrete. The variation of compressive strength with density of concrete was alternatively presented in Figure (7). The compressive strength of EPS concretes appears to decrease with a decrease in concrete density, or with the increase in the EPS volume percentage.

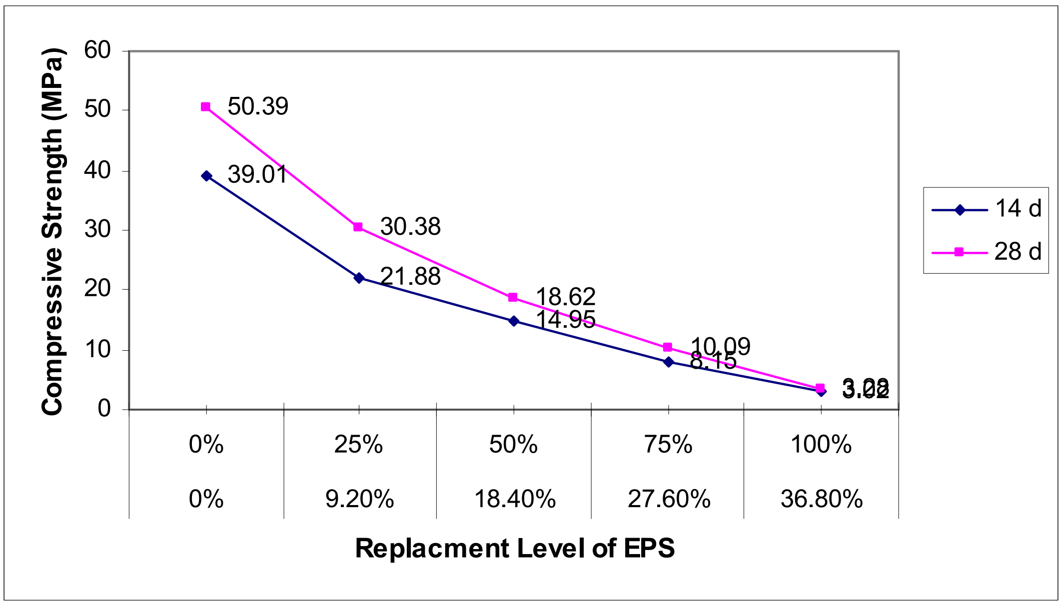


Figure 6: Effect of EPS on the compressive strength and development of compressive strength with age (100 mm cube)

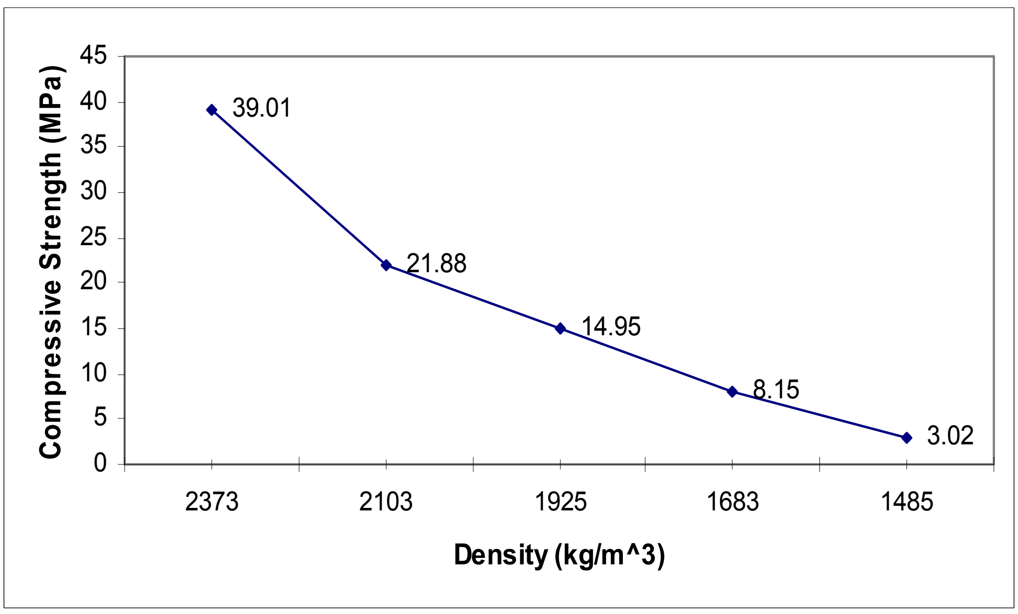
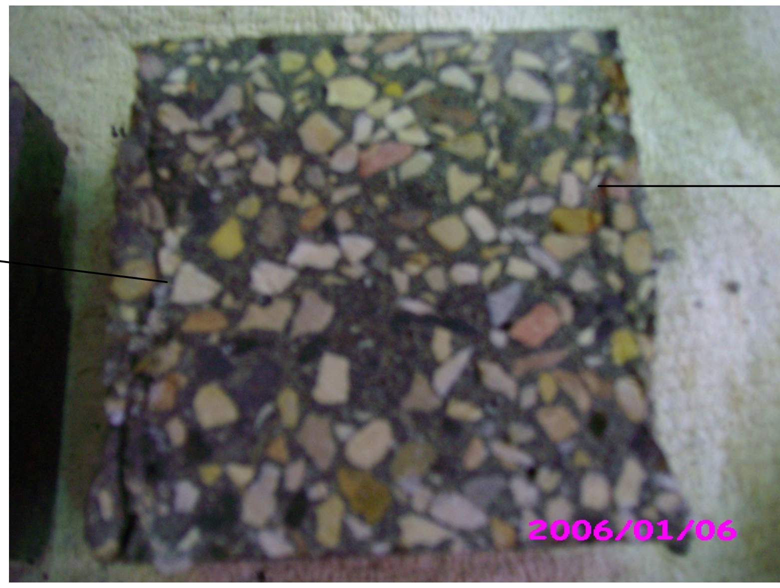


Figure 7: Relationship between measured compressive strength and measured density (100mm, 14 days)

The curing duration has a significant effect on the compressive strength. Increasing the duration time was found to increase compressive strength for all concrete mixes. The difference in compressive strength between 14 days and 28 days was decreased by increasing the percentage level of the EPS aggregates, and it becomes insignificant at 100% EPS.

Further more; specimens of different dimensions (150 mm cube) were tested during the experimental work to investigate if there is any effect of larger dimensions on the compressive strength and the failure behavior of expanded polystyrene concrete at the same curing conditions of 100mm cube. It was found that no differences in the behavior of the both specimen's dimensions of EPS aggregate concrete, (i.e.) as the volume percentage of EPS increased, both compressive strength, density decreased and the failure mode became more compressible.

Moreover, the failure mode of the concrete specimens containing EPS aggregates under compressive loading did not exhibit the typical brittle failure normally associated with conventional aggregate concrete as shown in Figure (8 a). But for EPS aggregate concrete, the failure observed was to be more gradual (more compressible), and the specimens were capable of retaining the load after failure without disintegration, as seen in the Figure (8 b) for 25% EPS.



(a) Conventional Concrete 0% EPS

(b) 25% EPS Concrete

Figure 8: Failure mode in compression test (100mm, 14 days)

The effect of water to cement ratio on compressive strength in 50% EPS concrete

Generally, concrete strength depends on the strength of cement paste, aggregate properties, and, the strength of the interfacial transition zone between the paste and the aggregate. This zone is shows in Figure (9), and its strength is dependent on water to cement ratio. The effect of water to cement ratio on the compressive strength of EPS at the age of 14 days for C-50% EPS mix is shown in Figure (10). A reduction in water to cement ratio from 0.55 to 0.4, resulted in an increase in compressive strength of polystyrene concrete from 11.3 MPa to 19.31 MPa since EPS aggregates are non-absorbent. It is evident that the water to cement ratio of expanded polystyrene concrete should be kept as low as possible to achieve the highest strength (see Table 2). For very low ratio the EPS granules do not adhere to dried cement paste well, because the filler is hydrophobic and its surface is statically charged. Low values for water to cement ratio may also increase the amount of entrapped air content due to incomplete compaction, since no attempt was made to isolate the effect of the entrapped air content on the measured strength.

Table 2: Compressive Strength vs. W/C (50% EPS, 100 mm Cube)

Compressive Strength (MPa)	Water to Cement Ratio
19.32	0.4
17.05	0.45
14.95	0.5
11.30	0.55

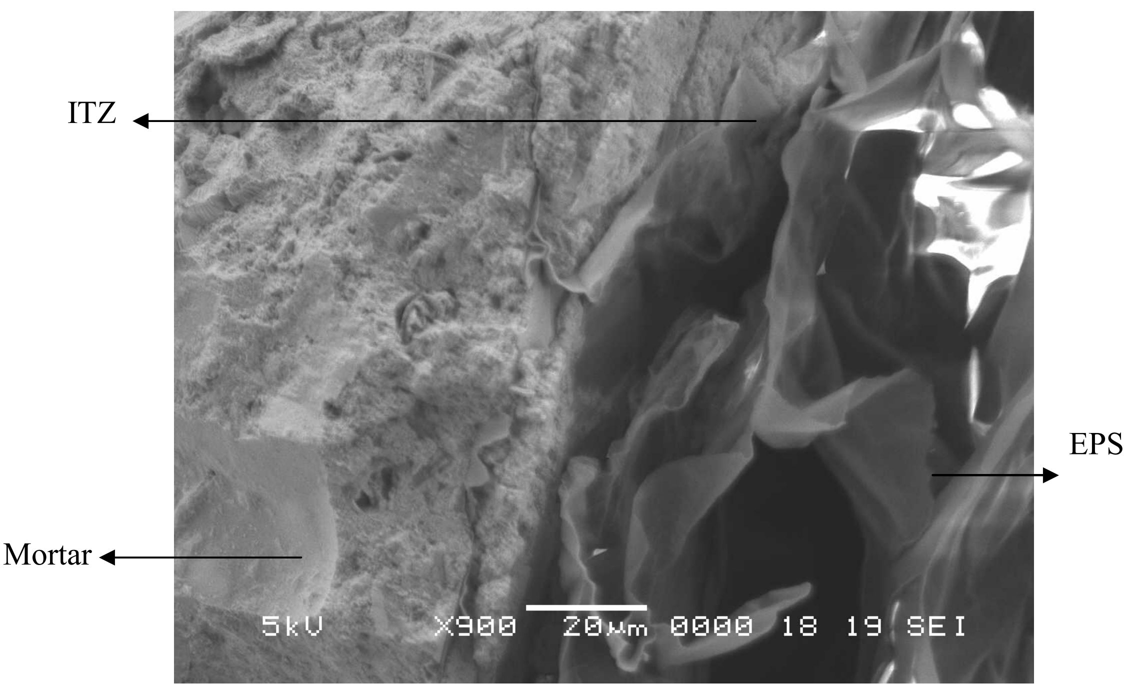


Figure 9: An SEM image showing the interfacial transition zone between EPS and mortar

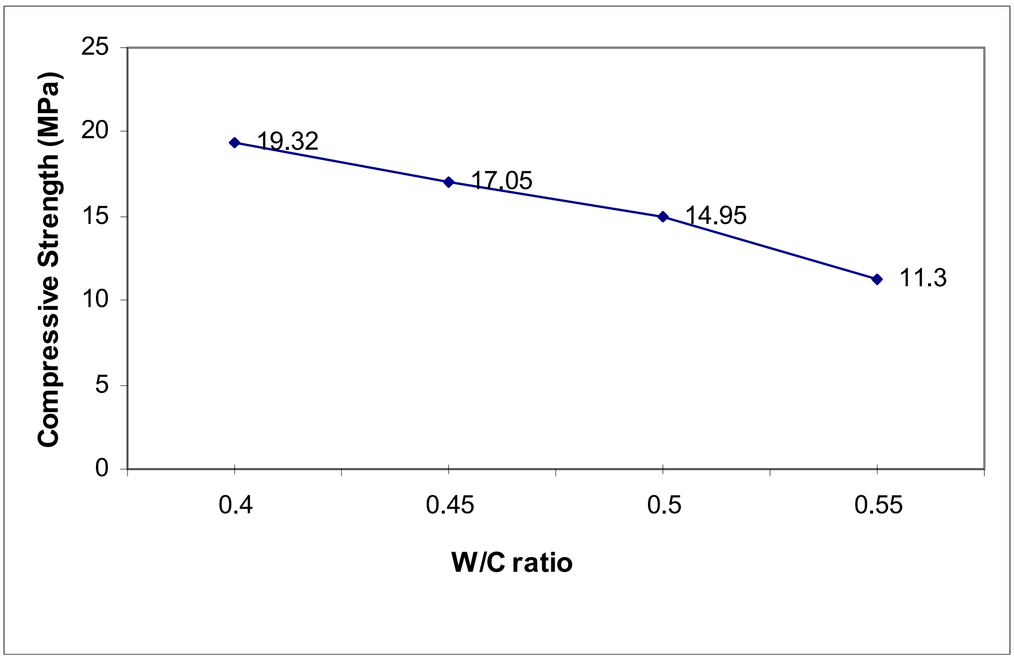


Figure 10: Effect of water to cement ratio on compressive strength (100 mm , 14 days)

Visual observations:-

- As the EPS aggregates content was increased, the fresh concrete mix became flexible, harsh, and difficult to place and compact.
- When the amount of EPS aggregate was increased, the specimens became easy to damage.
- Specimens of highest EPS aggregates level were still wet when they removed from the moulds after 24 hours.
- It was observed that the time required for the EPS aggregate specimens to dry before compression test was dependent on the amount EPS aggregate added, the higher the amount of EPS the longer the time required.
- Specimens of the highest amount of EPS aggregates tend to float for few seconds before being water immersed in curing process.
- Visual examination of the concrete slices has indicated that the EPS granules were uniformly distributed in the concrete matrix, except in the case of 100% EPS.

CONCLUSIONS

Recycled expanded polystyrene waste can be incorporated in conventional concrete by replacing the normal aggregate, either partially or fully and the level of replacement affected the engineering properties of concrete. The density of concrete could be adjusted with the use of lightweight expanded polystyrene granules to achieve the desired density and properties. The increase of polystyrene granules concentration in the concrete is directly related to decreasing of specimens' density. The compressive strength of polystyrene aggregate concrete is affected by the water to cement ratio. Therefore, the water to cement ratio of expanded polystyrene concrete should be kept as low as possible to achieve the highest compressive strength for specific percentage of EPS, which may increase the entrapped air content due to incomplete compaction.

The compressive strength of EPS concretes appears to increase with an increase in concrete density, or with decrease in the EPS volume. The variation of compressive strength with age showed a continuous increase in all the mixes. It was found that the compressive strength development seems to be higher at concretes of low volume of EPS aggregate.

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