International Journal of Engineering & Technology, 8 (1.1) (2019) 207-212

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Utilization of Styrofoam-Matrix for Coarse Aggregate to Produce Lightweight Concrete

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Abstract

A lightweight coarse aggregate called Styrofoam-Matrix Aggregate (StyM) was developed to use in Lightweight Aggregate Concrete Compositions. This paper aims to present the characteristics of the developed StyM aggrerate to replace natural coarse aggregates in lightweight concrete mixtures. The presented characteristics are the compressive strength and the collapse pattern obtained experimentally. The experiment used styrofoam formed into balls with diameters of 25 to 35 mm coated with matrix as the core materials in StyM. The measurements of the characteristics were conducted after 14 days completed mixture of StyM 10% as a controlled volume, and StyM 100% replacement for coarse aggregate. The testing was conducted to observe the concrete compressive strength and the corresponding collapse patterns. For the hard concrete StyM 10% with the density of 2183 kg/m^3, the compressive strength is 19.86 MPa, while for StyM 100% with the density of 1650 kg/m^3, which is considered as lightweigh concrete, the compressive strength is 12.02 MPa. The collapse pattern shows in the form of columnar. This paper found that the developed Styrofoam coated matrix (StyM) aggregate can form lightweight aggregate concrete mixtures with superior mechanical and durability properties.

Keywords: *Styrofoam, Aggregate, Lightweight-Concrete.*

1. Introduction

Styrofoam is also known as polystyrene or in Indonesia is usually called *gabus*. Styrofoam or *gabus* has been widely used in daily applications including packaging of electronic equipments such as: TV, radio, refrigerator, and some other small appliances to reduce direct impacts, storage of ice cubes, food packaging, handicrafts, printing materials, advertising materials because they are easily molded, mading boards, casting buildings, wall linings and building construction, insulation and sound dampening.

In food packaging, styrofoam is able to maintain heat and cold, easy to handle, preserve the freshness and integrity of the packaged material, low cost, safe, lightweight, prevent leakage and the shape remains unchanged.

The main ingredient of Styrofoam are polystyrene, a type of plastic that is very light, rigid, translucent, cheap and brittle. Because of its weakness, polystyrene is mixed with zinc and butadiene compounds, so it loses its clear nature and is milky white.

In order to improve the flexibility, plasticier substances are usually added such as dioctyltate, butyl hydroxy toluene, or n-butyl stearate. It has another appearance of small cell structures with the blowing process using chloro-fluorocarbon gas (CFC). The CFC gas compounds however may cause ozone holes on the atmosphere [1],[2]. A number of electronic equipment such as refrigerators and air conditioners are prohibited from using CFC materials.

In addition, the basic ingredients of the plastic monomer strine which contain toxins easily migrate and contaminate food. Styrofoam also has an impact on health, environment and global warming. One of the impacts in the form of waste after use is the solution to reduce Styrofoam, such as doing 3R (Reduce, Reuse, and Recycle).

1.1. Lightweight aggregates and lightweight concrete

In accordance with the development of science, technology, and information, currently, concrete technology has been very advanced and continues to grow rapidly following the trend of the needs of modern human life. Like towers of high-rise buildings, underground and underwater buildings, roads and bridges, and other buildings that continue to increase require concrete with a large quantity and high quality. Concrete technology is in tandem with the progress of its material-forming technology.

Concrete can be classified into two groups based on the density: namely normal concrete in the range 2200 to 2600 kg/m^3 and lightweight concrete in the range of 300 to 1900 kg/m^3. Lightweight concrete is principally obtained by reducing its density, replacing the solid material with air voids. These air voids can be found in natural aggregate grains such as pumice, in cement paste with an air inflating process is known as cellular concrete, and among coarse aggregates that do not use fine aggregates are known as no fine-aggregate concrete, as explained by Neville [3].

Neville [3] further defines the relationship between lightweight concrete and its strength. Concrete with density of 1350 to 1900 kg/m^3 is sutable for structural purposes. This concrete has a minimum compressive strength of 17 MPa and known as Structural Lightweight

Concrete. Concrete with density of 300 to 800 kg/m^3 is for non-structural purposes and especially heat retention, known as Low-Density Concrete. Concrete with density between 800 to 1350 kg/m^3 for heat retaining and other non-structural compressive strength 7 to 17 MPa, known as Moderate Strength Concrete.

There are some efforts have been reported to get lightweight concrete. The research works are Alqahtani et al. [4] used waste plastic as a substitute for aggregate, Xu et al. [5] used polystyrene as a substitute of aggregate in lightweight concrete and hollow brick mixes, Miller and Tehrani [6], Lu et al. [7] and Hunag et al. [8] used tire rubber instead of aggregate, Ayati et al. [9], Nepomuceno et al. [10], Pla et al. [11] and Yang et al. [12] used clay as a substitute for aggregate.

Some researched used natural resources, such as Farahani et al. [13] and Aslam et al. [14] used oil palm shell (OPS) from agricultural waste as an aggregate, Oktay [15] used various artificial and natural aggregates, Tchamdjou et al. [16] used natural light aggregates from Scoria Volcanic.

All reports using artificial light aggregates as done [4] to [15] show a trend of influence on the compressive strength decreasing, as compiled and compared by Shafigh et al. [17].

There is a paper [18] that informs about the use of styrofoam in architectural or non-structural fields that receive low loads and substitutes for fine aggregate (sand), using styrofoam in a brick-foam mixture, whose compressive strength reaches 5 MPa. Whereas Giri et al. [19] using styrofoam with a grain diameter of 3-10 mm as much as 0%, 10%, 20%, 30% and 40% as additional material for concrete mixtures. The results show a decreasing trend in strength. This is different from the paper we write, Styrofoam on our paper is 1. As coarse aggregate with a grain diameter greater than 4.5 mm, 2. Styrofoam granules coated, 3. As a substitute for 100% coarse aggregate not as an additive from concrete mixture, 4. The effect on compressive strength is not on split strength and flexural strength.

The added value of styrofoam as aggregate is in the form of recycling waste material that makes the environment green and material sustainable.

1.2. Aggregates of Styrofoam-coating (StyC)

This paper focuses on the use of styrofoam as coarse aggregates. When the volume is dense (not air voids) coarse aggregates are replaced by lightly controlled materials, of course, light concrete is obtained. But the problem is that the compressive strength is small and what material is light to replace the solid volume of aggregate? Stryrofoam is a solid material that has the properties of being very light, elastic and unable to withstand the load of the structure. Stryrofoam / polystyrene is a good material in terms of mechanics, such as tensile strength up to 40 MN/m^2, flexural modulus to 3 GN/m^2, shear modulus up to 0.99 GN/m^2, poisson number 0.33. It has a specific gravity of up to 1050 kg/m^3, is rather brittle and soft at temperatures below 100 ° C [19].

Paying attention to the above behavior, this research utilized Styrofoam as a substitute for solid volumes of concrete with certain compositions. This research also solved the problem in casting Styrofoam always floating.

To overcome this, styrofoam was coated with a thin solid material so that this balls are not floating on the surfave but distribute evenly in the mixture. This invention is a new lightweight coarse aggregate, called styrofoam-coating aggregate (StyC), which will be used and developed in the composition of lightweight aggregate concrete.

This paper aims to present the initial feasibility of styrofoam matrix (StyM) innovation in lightweight aggregate concrete mixtures in terms of compressive strength and collapse patterns.

2. Methodology

The method used to determine the feasibility of StyM aggregates is to make lightweight aggregate concrete specimens with a StyM aggregate mixture of 10% replacing the concrete volume. The mixing Styrofoam was done layer by layer in the sample mold so that StyM distributed evenly in the sample and its strength is not affected by the irregular aggregate position.

Using a StyM 100% aggregate mixture replaces the coarse aggregate volume and without adjusting its placement. Both types of the mixture were weighed and the compressive strength testing was conducted to determine the type and strength of the lightweight concrete including the classification of the group defined in [3].

And at the same time, the observations of the collapse and the condition of the StyM aggregate were carried out after compressive strength testing. Furthermore, a normal concrete test object was also made to compare with the results of StyM aggregate concrete.

3. Experimental

The initial step of the experiment in the laboratory, preparing Styrofoam material was formed by balls with a diameter of 25-35 mm and then coated with a matrix composing of the water-cement ratio 0.45. The styrofoam-matrix (StyM) aggregate was ready after completing the 14 days drying time of the matrix.

The second step, examination of all concrete forming materials, including the physical properties of StyM. Using a mixture composition consisting of Cement as much as 377.19 kg/m^3, water 215 kg/m^3, sand 588.63 kg/m^3 and coarse aggregate 625.05 kg/m^3 as a comparison and replaced by 100% lightweight aggregate StyM 245.02 kg/m^3.

The composition of StyM 10% is comparable with the volume of a cylindrical concrete consisting of 24 granules/ball StyM that are placed regularly in the sample mold. Each layer is composed of 4 StyM balls.

Concrete is treated in water with a temperature of 29 ° C ± 1 ° C, continuously and then compressive strength testing at 28 days. Weighing the weight of the sample before being treated and when testing compressive strength. The final step, observing the collapse of the concrete sample when tested compressive strength.

4. Results and Discussions

Fig.1 shows Styrofoam was initially cut into squares then made into balls with a diameter of 25 - 35 mm. This shape adjustment of 100 pieces reduced the weight from 0.0376 kg to 0.0162 kg or a 57% reduction. Fig. 2 shows the balls after being coated with a matrix into a

Styrofoam-matrix aggregate named StyM. The weight increased to 1.174 kg or an increase of 72.5 times the weight of a Styrofoam balls. This StyM is however still very light to replace the normal aggregrate of the concrete.

Fig. 1: (a) Styrofoam in the shape of a cube, (b) Styrofoam in the shape of a ball.

Fig. 2: Styrofoam-coating with matrix (StyM)

4.1. Density and Compressive Strength of Concrete StyM

Fig. 3: Pengaturan letak butiran StyM 10%.

Fig. 3 shows StyM aggregates arranged in each layer as many as 4 pieces and as many as 6 layers of each concrete cylinder, a total of 24 pieces with a calculation of the volume reduction of concrete cylinders as much as 10% x 5300 cm^3 = 530 cm^3. The diameter of StyM granules is a maximum of 3.5 cm, with a volume of 22.4 cm^3, the number of grains 530 / 22.4 ≈ 24 in each cylinder is obtained. It should produce lightweight concrete, reduce concrete volume by at least 15% or as many as 36 StyM granules. When arranged in 6 layers, the distance between StyM grains becomes tight. As a result, the natural coarse aggregate distribution cannot fill the gap between StyM grains. When using StyM 3.0 cm in diameter, 57 pieces of StyM granules are needed and if 2.5 cm in diameter, 98 pieces in one cylinder. Paying attention to this will certainly have difficulty in arranging StyM grains each layer and between layers.

Table 1 shows the use of 10% StyM obtained concrete density to 2183 kg/m^3, this result is not included in the lightweight concrete class because it is greater than 1900 kg/m^3. When compared with StyM 0% normal concrete density of 2304 kg/m^3 obtained a density reduction of 5%.

In this case, the initial assumption of a 10% reduction in concrete volume will reduce 10% of normal concrete density (2200 kg/m^3) equal to 220 kg/m^3, the density obtained should be 2304 - 220 = 2084 kg/m^3, while the experimental results 2183 kg/m^3.

The assumption to reduce concrete density by reducing the volume of concrete replaced by StyM granules is not accurate. It is shown that the use of StyM aggregate as much as 10% replacing the volume of concrete resulting in a density reduction was only 5%. This is because the compaction of the concrete is relatively unequal and when the StyM aggregate was not equally distributed so that it cannot be compacted properly.

Table 1: Category Concrete

Contents StyM	Density (kg/m^3)	Compressive Strength (MPa)	Category Concrete
StyM 0%	2304	28.71	Normal
StyM 10%	2183	19.86	Norrmal
StyM 100%	1650	12.02	Lightweight

Concrete StyM 10% has a compressive strength of 19.86 MPa and is included in the concrete structure because it is larger than 17 MPa. When compared with normal concrete, the compressive strength has decreased by 30.8%, this shows the magnitude of the StyM influence on the strength of the concrete.

Furthermore, aggregate StyM100% replaced all coarse aggregates and obtained a density of 1650 kg/m^3, including the category of lightweight concrete because it was smaller than 1900 kg/m^3, or a reduction in density of 28.4%.

Concrete StyM 100% produced a compressive strength of 12.02 MPa and classified as non-structural concrete because it was in 7 and 17 MPa. When compared with normal concrete, the compressive strength decreased by 58.1% or 1.9 times the decrease in StyM 10%. The decrease in the compressive strength of the StyM concrete is inseparable from the uniform aggregate gradation or "graded gap" and the StyM aggregate strength is still low when compared to natural aggregates. For this reason, it is necessary to make changes to the grain gradations to conform to coarse aggregate distribution standards. In the coating, matrix strength is increased by adding cement admixture material or adding another layer or replacing the coating with a mortar coating.

A combination of other materials that have greater strength obtained a compressive strength of 12.02 MPa and classified as non-structural concrete because it was in 7 and 17 MPa. When compared with normal concrete, the compressive strength decreased by 58.1% or 1.9 times the decrease in StyM10%.

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4.2. Collapse Pattern of Concrete StyM

Fig. 5: Collapse Pattern of Concrete StyM10%

When the concrete sample receives the maximum load, the concrete will collapse, starting with the part of the concrete that has the weakest strength and will appear crushed, as in mortar or on coarse aggregate or loose coarse aggregate from mortar or its combination. The collapse pattern can be cone, cone and split, cone and shear, shear, columnar or other combinations.

Fig. 5 shows generally concrete StyM10%, a pattern of collapse that occurs in the form of columnar (a) and columnar and shear (b). Seen the concrete cylinder is still intact and does not directly see the influence of the StyM aggregate, is it damaged in the coating or other parts?

Fig. 6 shows that concrete StyM100% has a columnar pattern collapse, it can be seen that StyM aggregates are crushed on the matrix coating and detached from the styrofoam and the release of StyM from the mortar. In addition, Styrofoam material is not damaged or deformed. This condition indicates the strength of the matrices is relatively weak compared to the stress acting on the surface, and the strength of the bond is weak between the matrix-coating with the mortar or with the styrofoam. In addition, it is seen that the deployment of StyM aggregates in distilled concrete is sufficiently good throughout the cylindrical chamber and StyM intergroup space is filled with mortar with a consistent distance and no visible StyM collected at one particular location. Thus, it is necessary to increase the strength of the coating as mentioned above. Increases the bond strength between coatings and styrofoam, with the way the Styrofoam surface is made rough. Given that the size of the StyM aggregate is relatively uniform, all of the gaps are filled with mortar material and mortar looks more strongly fill the gap.

In a comprehensive manner, the concrete StyM collapse begins from the destruction of coating-matrix StyM and the release of bonds StyM with styrofoam then with mortar, forming a columnar pattern.

Fig. 6: Collapse pattern of concrete and deployment of aggregate StyM100%

5. Conclusion

Styrofoam matrix (StyM) aggregates as artificial lightweight coarse aggregates are aggregate innovations that feasible to be developed as lightweight aggregate alternatives, contribute to preserving the environment from the impact of styrofoam, and have the potential to produce lightweight concrete.

The strength of StyM depends on the strength of the coating. This paper uses a matrix with normal composition without admixture material, so that its strength can be increased or replaced with mortar or coating material again with other materials.

Styrofoam used can be selected according to its density function and the surface is rather rough to increase the strength of bond StyM. The improvement produces lightweight stryrofoam-coating concrete (LSCC) with a compressive strength of more than 17 MPa for concrete structures.

Controlled volume method, adjusting the placement of StyM in a cylindrical chamber with the right amount, for replacement of aggregate that is not 100% but having difficulty in applying it to aggregates with smaller diameter sizes.

The research can be further extended on the feasibility of lightweight styrofoam-coating aggregates (LSCA) according to the lightweight concrete technology.

Acknowledgement

The authors would like to thank Assoc. Prof. Dr. Waluyo Adi Siswanto who has directed and guided the writing of this paper. Also our gratitutes to Prof. Bambang Setiadji, the Rector of Universitas Muhammadiyah Kalimantan Timur who are very supportive towards international publications.

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