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Utilization of polystyrene waste for wall panel to produce green construction materials

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Abstract

The wall structure separating floor areas significantly contribute the weight of the building that put it into a greater risk to earthquake event. The use of lighter wall materials is more desirable to reduce the potential risk of damage due to earthquake treat. This development of polystyrene wall panel is an effort to achieve two objectives, namely development light wall material and promoting green construction materials by utilizing polystyrene waste. The paper present the study on the development of polystyrene waste wall panel by pre-compacted method. In this research, the shredded polystyrene was blended with cement Portland and water at various certain proportion. When the mixed already properly blended, it was poured into the steel mold of 30x80cm. The mixed within the mold was subjected to compaction stress for up to 2 MPa that reduce the thickness of the mixed into about 1 cm. The polystyrene panel was kept in the humid zone for curing for about 28 days. They were 12 wall panel specimens made for this purpose. Result of test show that at the same compaction stress, higher cement content produces stronger polystyrene concrete. The average compressive strength of specimens with 250 kg/m^3 and 300 kg/m^3 cement content are 4.9 MPa and 5.3 MPa, respectively, and for flexural strength are 2.4 MPa and 3.3 MPa, respectively. The result show that the compressive strength of concrete matrix and flexural strength panel are significantly high. However, under repeated loading of about 10% of maximum load, the panels experience decrease in stiffness in each load cycles suggesting the low tensile capacity of the concrete matrix. These results indicate the potential use of polystyrene wall panel for construction materials purposes with further attention on improvement the tensile characteristic of the concrete matrix.

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1. Introduction

Wall is one component of building structure that is generally made of bricks, concrete blocks, concrete panels, wood boards, plywood and gypsum. The use of brick, concrete brick and concrete walls will produce large self-weight of wall resulting in large building's dead weight. The use of lighter wall materials is more desirable to reduce the potential risk of damage due to earthquake treat. To reduce the dead load of building, lighter weight wall has been widely used, such partition walls from plywood or gypsum. This study is attempted to take advantage the nearly weightless polystyrene waste into light weight wall panels. Polystyrene waste is well known as waste material that is hardly decomposed by nature. In a view of nature conservation, this situation is alarming since the volume of this waste is increasing by time. It is expected that this research will be able to bring a hope of the potential utilization of waste polystyrene as environmentally friendly building materials to support nature conservation efforts. This study has been started for quite a while but has not been able to produce some potential finding worth to be developed. The potential use of polystyrene waste began to appear with the application of pre-compaction processes in the manufacturing process of wall panel specimens. The polystyrene used in this study is limited to polystyrene from the pack of electronic goods.

2. Research objectives

The long term objectives of the research is the utilization of polystyrene waste as construction material thereby developing a green concept in construction program. This paper presents the extent of research result. The more detail of the objective of study presented in this paper are as follows:

- Developing procedures for processing polystyrene waste into a lightweight concrete based construction materials.
- Studying the mechanical characteristics of polystyrene wall panel, such as compressive strength, flexural strength, density, water absorption,
- Studying the behavior of polystyrene wall panel under repeated load to simulate the action of forces on wall.

3. Literature review

Lightweight concrete is defined in the literature as concrete with bulk density of less than 1800 kg/m^3 [1]. Research on the development of lightweight concrete has been widely carried out, and one of an attempt to achieve a lightweight concrete is to replace aggregate with nearly weightless polystyrene [2-7]. There are several studies of lightweight concrete using polystyrene waste. Musana (2006) carried out research where the polystyrene was cut into small cube shape of less than 1 cm to replace the coarse aggregate [2]. Various PCC cement proportion of 250 kg/m^3, 300 kg/m^3 and 350 kg/m^3 was used. The test results showed that compressive strength of polystyrene concrete is very low (<1 MPa). Ndale (2010) conducted study on the use of polystyrene into wall panel of concrete with various thickness of 6 cm and 8 cm [3]. The concrete polystyrene panel was reinforced with wire mesh of 4 mm diameter. The result of study showed that the flexural strength of panel is too low (flexural strength <1 MPa). Atmoko (2012), Aidil (2012) and Siregar (2012) conducted similar study and they introduced pre-compacting process in casting panel specimens [8,9]. Unfortunately, the wooden mold used for casting was capable only to withstand limited pre-compaction forces and hence the result of specimens were also unsatisfactory.

3.1. Wall panel

The idea of utilization of polystyrene waste for wall panel come from the availability of light wall panel products that basically consists of super foam sandwiched between steel wire mesh and concrete. One of factory product of polystyrene wall panels is M-System, originally developed in Italy (www.M-Systemindonesia.com) [10]. M-System wall panels consists of thick super foam core reinforced with wire mesh and concrete at both surfaces than for residential house, high rise buildings and special applications such as swimming pools, tribunes and others. The M-system panel is bearing wall that can be used for up to four floors of building structure. The panel wall size of 15 cm x 270 cm x112cm is capable to sustain load up to 1,700 KN. Another product of lightweight wall concrete panels is

Qui Panel which has a density of 700 kg/m^3 [11]. Qui panels have a core made of a mixture of cement and EPS (Expanded Polystyrene) and coated with fiber cement. Qui Panel can be used for external walls, roofs, floors, partition walls. It can be used as a load bearing wall for one and two-story buildings.

3.2. Three Dimensional Steel Wire Mesh Panel

In Indonesia, the use of lightweight wall of super foamed based is stipulated in SNI 7392:2008 [12]. The lightweight wall system is called Three Dimensional Steel Wire Mesh Panel (PJKB-3D) which consists of expanded polystyrene core reinforced with steel wire mesh. The wall panel system is similar to M-System. PJKB-3D acts as a load bearing wall or floor plate and can be used for building. Steel wire existing on both sides are plastered using mortar with minimum cement content of 250 kg/m^3 (proportion of cement: sand = 1: 4) to result in a minimum compressive strength of 17.5 MPa. The EPS (Expanded Polystyrene) has minimum density of 16 kg/m^3 and thickness of 40 mm to 150 mm. The wall can serve as a barrier to noise and temperature. The thickness of one side plaster is 40 mm up to 50 mm that result in thickness of the entire wall panel of 120 mm to 250 mm.

The initial stage of research was tried to imitate the fabricated wall panel system by introducing polystyrene concrete of wall core. Despite numerous trial have been carried out, but the result is still unsatisfactory owing the poor quality of polystyrene concrete. It is only after the application of pre-compaction process that the quality of polystyrene concrete seems to be promising for further development. Owing to limited strength of polystyrene concrete, the latter research is not focusing to use polystyrene wall panel for bearing purposes but rather for partition to substitute wooden or gypsum panels.

4. Materials, specimens and testing

The research process was carried out into three main stages, namely the examination of materials, manufacturing of specimens and the testing of specimen. The examination process included evaluation of cement condition and investigation the unit weight of polystyrene. The second stage of research include a trial mix to determine adequate proportion of PPC cement and polystyrene, formulating procedures mixing and preparing specimen to investigate mechanical properties of polystyrene concrete used for research. The last stage was testing to investigate both mechanical properties and also strength characteristic of lightweight polystyrene wall panels.

This research used Portland Composite Cement (PPC) with proportion of 250 kg/m^3 and 300 kg/m^3 and water cement ration 0.3. The water cement ratio is determined considering the result of previous research. In the application of pre-compaction process, the use of higher water cement ration will result in more bleeding during the pre-compaction. The polystyrene used in the research is a type of polystyrene waste from packaging electronic goods so that it is relatively hard and stiff. Using shredding machine, the polystyrene was made into tiny shredded shaped with average length of less than 1 cm. The shredded polystyrene is nearly weightless so that it is easy being blown by air and is kept under dry condition until prior mixing process. The mold for casting specimen is steel mold from steel plate of 6mm thickness and has dimension of 80 cm length, 30 cm wide and 30 cm height (Fig. 1). After pre-compaction at 2 MPa, the resulted specimen of polystyrene concrete panel is 80 cmx 30 cm x 1 cm. The specimen was then placed in the humid area for curing for at least 28 days when it is ready for testing.



Fig. 1. Steel mold for casting specimen made of steel plate of 6 mm thick.

The experiment was initiated to find appropriate polystyrene concrete mix to be used for panel. During concreting process, the mixing of shredded polystyrene was very tricky since the polystyrene dry and is easy to fly. Therefore, the polystyrene need to be poured into the mixing bowl slowly with extra care. Cement and water of certain amount according to the intended proportion were then poured into the bowl and was mixed slowly for about 5 minutes. A proper mix was achieved when all shredded polystyrene was fully covered with cement paste. The mix was then poured into steel mold into 3 stage, each stage about 10 cm height and compacted using steel stick with round end. When the mold is full, the surface was trimmed to make it flat and uniformly thick. The mold cover was put in place, and then the mold was placed in the steel frame for application of pre-compaction. Attention should paid so that the point of loading at the mold cover coincide with its center area to ensure uniform distribution of forces in the mix within the steel mold. The forced was gradually applied through hydraulic jack connected to data logger were the load can be monitored. The loading process was stopped when the stress reached 2 MPa. The application of pre-compacting process on concrete panel is shown in Fig. 2a. The resulted polystyrene concrete panel after pre-compaction is shown in Fig. 2b.



Fig. 2. (a) The application of pre-compaction process in manufacturing polystyrene concrete panels; (b) The resulted polystyrene concrete panel from pre-compaction process.

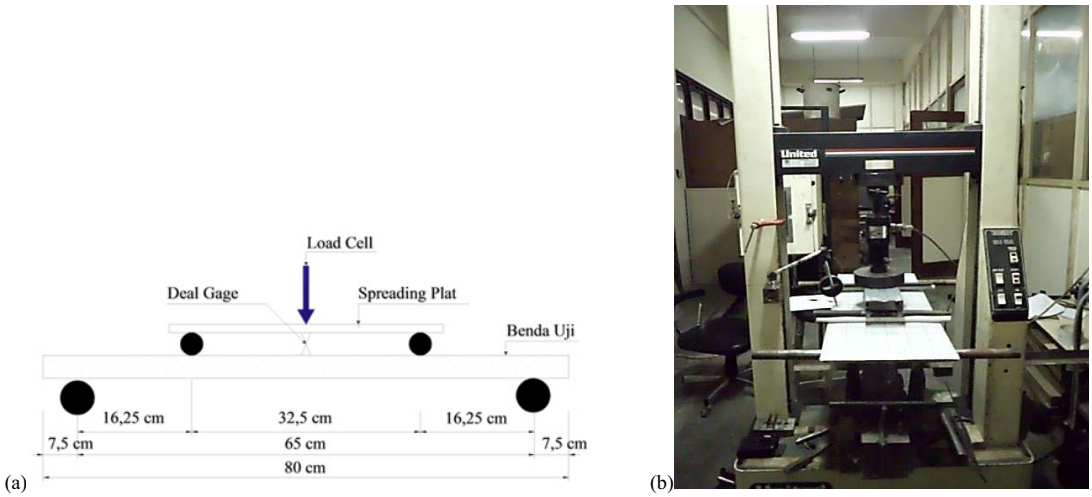


Fig. 3. (a) Schematic flexural test for polystyrene concrete panels; (b) Configuration of polystyrene concrete panel under flexural test

After all the specimens were made and appropriately cured in humid area for at least 28 days, the next stage was the testing process that include investigation of mechanical properties concrete matrix and strength characteristics of polystyrene concrete panels. The physical and mechanical properties of polystyrene concrete tests carried out on cube specimens of 5cmx5cmx5cm and cube specimens of 10cmx10cmx10cm, respectively that include the determination of water content, water absorption and compressive strength. While testing on wall panels were intended to investigate the compressive and flexural strength of panel, and the panel behavior under repeated loading. Fig. 3 shows the configuration of flexural test of panel, while Fig. 4 shows the set-up of test for panel under compressive load.

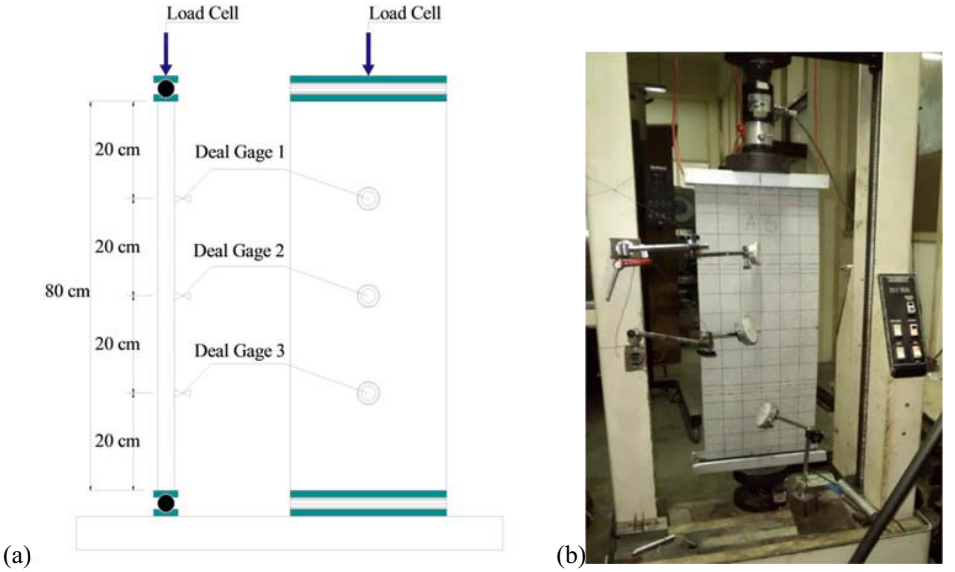


Fig. 4. (a) Schematic test set-up of polystyrene concrete under compression; (b) The testing configuration of polystyrene concrete panel under compression.

5. Results and Discussions

5.1. Results of physical and mechanical properties

The results of tests show that the unit weight of polystyrene in dry conditions being used in the research is 15.9 kg/m^3. The study also indicates that there are many variety of polystyrene with different unit weight. The use of polystyrene of different type might result in difficulties in assessing its unit weight and hence may jeopardize the uniformity of one concrete mix to another. As a result, the physical and mechanical properties of each specimens might be different one to another. Therefore, in order to minimize the diversity of the mixes, the polystyrene waste was collected from one source and from one type of package, namely packaging of electronic goods.

The physical test results show that the water content of polystyrene concrete with 250 kg/m^3 and 300 kg/m^3 are 7.20% and 6.68%, respectively. Meanwhile, the value of water absorption of mix with cement content of 250 kg/m^3 and 300 kg/m^3 are 9.27 % and 8.23 %, respectively. Polystyrene concrete mixes with higher cement content tend to have lower water content as well water absorption. This is might be attributed to the volume of polystyrene, where a mix with higher cement content use less polystyrene, hence less wet surface area during mixing and also less porosity. It is suggested that the water content and water absorption will indicate the characteristics of mix against humidity change that may lead to strength deterioration when the water content and water absorption are high. Referring to the technical requirement of plywood [13], where the water content should be less than 14%, the polystyrene concrete panels have values that meet the requirement.

Another results show that the bulk density of polystyrene concrete mixes with cement content 250 kg/m^3 and 300 kg/m^3 are 1,467 kg/m^3 and 1,533 kg/m^3, respectively. The result of bulk density of polystyrene concrete mix under pre-compaction stress of 2 MPa are significantly greater that the results of previous studies without pre-compaction [2-9]. The result also suggests that the density of mix tends to be close to the density of cement, and referring to previous study, it is suggested that the higher pre-compaction stress will result in mix's density that is closer to cement.

5.2. Compressive strength

The test results show that the compressive strength of polystyrene concrete mixes with cement content of 250 kg/m^3 and 300 kg/m^3 are 4.9 MPa and 5.3 MPa. This resulted compressive strength of specimens under pre-compaction stress of 2 MPa is significantly higher than the previous research without pre-compaction process since the concrete matrix becomes denser. According to lightweight concrete classification given by Neville and Brooks (1987) [1], the polystyrene concrete used in this might be included as type of lightweight concrete for retaining heat (insulating concretes).

5.3 Polystyrene concrete Panel Testing Results

Results of experimentation show that polystyrene concrete panels with cement content of 250 kg/m^3 and 300 kg/m^3 have an average weight of 14.4 kg/m^2 and 14.9 kg/m^2, respectively. These values are about 3 times than that for gypsum panel (5.5 kg/m^2). However, in comparison with the weight of red brick wall (250 kg/m^2) and also hollow concrete blocks (200 kg/m^2), the weight per square area of polystyrene concrete panel is still significantly lighter.

5.3.1. Compressive and Flexural Strength of Polystyrene Panels

The compressive test was carried out according to SNI 7392:2008 [10] for testing wall panel for structural purpose. Meanwhile, in the current research the specimen is of 80cmx30cmx1cm, hence the specimen is very slender (Fig. 4b). The results of test show that the polystyrene concrete panel with cement content of 250 kg/m^3 and 300 kg/m^3 have average compressive strength of 0.63 MPa and 0.83 MPa. The resulted compressive strengths are so low that make the polystyrene concrete panel is not available for bearing wall purposes.

Results of flexural test of polystyrene concrete panel yield average stiffness values of 17 N/mm and 31 N/mm for cement content of 250 kg/m^3 and 300 kg/m^3, respectively. While the average flexural strength of panels are 2.4 MPa and 3.3 MPa for panels with cement content of 250 kg/m^3 and 300 kg/m^3, respectively. The resulted flexural strength is significantly larger than previous research on flexural strength of gypsum [14]. The results of this study suggests that by increasing cement content can improve strength as well as stiffness of polystyrene concrete panels.

5.3.2. Panel Behavior under Repeated Loading

Repeated loading is intended to simulate the imposed load on the wall. This testing was carried out under flexural test at load level of 10% from the maximum bending load. Repetition was carried out up at the total of 20 cycles. In each load cycle, a curve describing the relationship between load (P) and deflections (δ) was obtained. The results of repeated load tests on the panel with cement content of 250 kg/m^3 and 300 kg/m^3 is shown in Fig. 5a. In Fig. 5a, each line of (P-δ) relationship shows one loading cycle. Each line is shifted to another due to a shift of the LVDT readings during to pause between one cycles to the next loading cycle. The flexural stiffness of panel is determined as value of slope at each line. To clarify the extent change in slope of every loading cycle, the magnitude of slope of each line is then drawn in accordance with the order of its loading cycles, and the result is shown in Fig. 5b. Fig. 5b clearly shows that the value of slope is decreasing from cycle to cycle indicating the decrease in stiffness of panel in every loading cycles. The decrease in stiffness of polystyrene panel might be attributed to the occurrence of micro raking within the concrete matrix. The crack propagates, as shown by further decrease in slope in the next cycle, as the load was repeated. This finding is very important in understanding the behavior of polystyrene panel as it

experience micro crack propagation under relatively low level of repeated loading (10% P_{max}). It can be concluded that the tensile strength capacity of polystyrene concrete matrix is low that result in panel of low stiffness.

The results of repeated testing for polystyrene concrete panel with cement content of 300 kg/m^3 also exhibits similar characteristics of decreasing stiffness in every load cycle. The rate of decrease in stiffness for mix with cement content of 300 kg/m^3 is nearly similar to that of lower cement content. The results of this study suggests that the polystyrene concrete panels has insufficient strength and stiffness to sustain repeated load as low as 10% of its maximum flexural capacity that might occur in wall structure. However, the flexural test results show the significantly high flexural strength of panels that indicates its potential to be further developed as wall panels. In further research efforts are required to improve the tensile capacity of concrete matrix, for example by adding fiber in the concrete mix or introduction of reinforcement either paper based or wire mesh on panel surfaces to improve its flexural strength and stiffness.

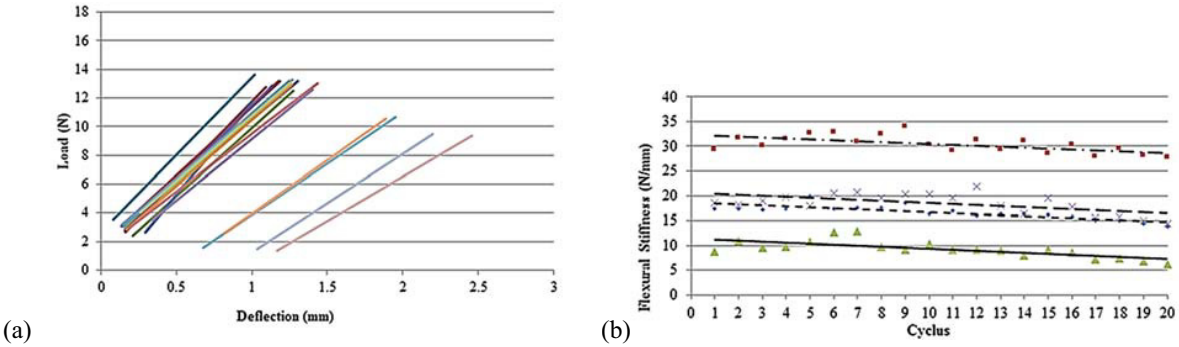


Fig. 5. (a) The relationship between P - Δ for each cycle of loading on the panel with cement content of 250 kg/m^3; (b) The change in slope in every loading cycle as drawn according the order of occurrence.

6. Conclusion and Suggestion

Based on the results of this study, some conclusions can be drawn as follows:

- The application of pre-compaction method in concreting process can effectively improve the mechanical characteristic of polystyrene concrete.
- At the same level of pre-compaction stress, the higher cement content on mix of polystyrene concrete may increase strength, reduce water content as well as and water absorption.
- Polystyrene concrete panel under pre-compaction stress of 2 MPa has significant flexural strength and stiffness indicating its potential to be developed as lightweight wall panel of non-bearing type.
- Polystyrene concrete panel exhibits decrease in stiffness under repeated loading suggesting the low tensile capacity of the concrete matrix that need further improvement.

The research finding suggest that one of the main disadvantage of polystyrene concrete is the low tensile capacity of the concrete matrix. Therefore, considering the potential utilization of polystyrene waste for construction materials, further efforts should be addressed to improve the tensile characteristics of concrete matrix, such as:

- The use polystyrene of smaller particles to increase bonding surfaces and bonding concrete matrix.
- The addition of fibers within concrete mix to improve tensile characteristics of polystyrene concrete matrix.
- The application of reinforcement on surfaces panels, such as wire mesh or membrane from plastic or paper based.

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