AN EXPLORATORY COMPRESSIVE STRENGTH OF CONCRETE CONTAINING MODIFIED ARTIFICIAL POLYETHYLENE AGGREGATE (MAPEA)

J Hadipramana[1,2,3a], S N Mokhatar[1,2,b], A A A Samad[1] and N F A Hakim[1]

[1]Faculty of Civil and Environmental Engineering Universiti Tun Hussein Onn Malaysia, 86400, BatuPahat, Johor, Malaysia
[2]Jamilus Research Centre, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor, Malaysia
[3]Research, Innovation, Commercialization, Consultancy Office, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia

E-Mail: [a]josef@uthm,edu.my and [b]shahruln@uthm.edu.my

Abstract. Concrete is widely used in the world as building and construction material. However, the constituent materials used in concrete are high cost when associated with the global economic recession. This exploratory aspires to have an alternative source of replacing natural aggregate with plastic wastes. An investigation of the Modified Artificial Polyethylene Aggregate (MAPEA) as natural aggregate replacement in concrete through an experimental work was conducted in this study. The MAPEA was created to improve the bonding ability of Artificial Polyethylene Aggregate (APEA) with the cement paste. The concrete was mixed with 3%, 6%, 9%, and 12% of APEA and MAPEA for 14 and 28 curing days, respectively. Furthermore, the compressive strength test was conducted to find out the optimum composition of MAPEA in concrete and compared to the APEA concrete. Besides, this study observed the influence and behaviour of MAPEA in concrete. Therefore, the Scanning Electron Microscopy was applied to observe the microstructure of MAPEA and APEA concrete. The results showed the use of high composition of an artificial aggregate resulted inferior strength on the concrete and 3% MAPEA in the concrete mix was highest compressive strength than other content. The modification of APEA (MAPEA) concrete increased its strength due to its surface roughness. However, the interfacial zone cracking was still found and decreased the strength of MAPEA concrete especially when it was age 28 days.

Keywords: MAPEA, APEA, plastic waste, Polyethylene aggregate, green concrete

1. Introduction

The material an extremely popular in construction field such as concrete is composed of natural granular aggregate mixed with cement or binder. The composite material of concrete is increased its strength when the coarse aggregate stick together and the fine aggregate fills the space between them further hardened by cement hydrolysis. Recently, the global economic recession made natural materials is highly valued because supply limited. Furthermore, some alternatives solution to substitute natural composition of material concrete especially the aggregate were proposed. In the same time, there are abundant of plastic wastes disposed in our daily life every day. Hence, the environment very threatened by the existence of plastic garbage an increasingly large. Therefore, this problem give the motivation that the reuse/recycle waste materials especially plastic waste represents to alleviate the problem of solid materials management [1]. Utilize the plastic waste and recycling it to create a new material for substitution natural aggregate concrete is the one of the best solution to reduce the plastic disposal plastic problem beside, which friendly the environment also very economical advantage. That would certainly reduce the use of natural resources to aggregate.

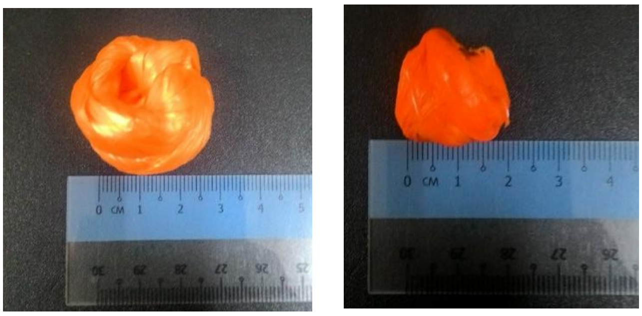
Previous research such as Pezzi, et al. [2], Jo, et al. [3], Hınıslıog˘lu & Ag˘ar [4] reused the waste plastic for concrete industries. They added the plastic waste into concrete related to get the new perspective of research activity also to give a view of integrating areas of concrete and environmental technology. Hınıslıog˘lu and Ag˘ar[4] investigated that the polymer additives to asphalt concrete from the plastic waste containing High Density Polyethylene (HDPE) provided the better resistance against permanent deformations. Tam & Tam [5] stated that the technology developing in building materials is the technology that will progressively use plastic recycling in order to increase its properties such as durability, strength and an appearance. Jo, et al. [3] investigated that the concrete using an unsaturated polyester resin based on recycled plastic waste of Polyethylene Terephthalate (PET) increased the compressive strength and flexural strength. In addition, this investigation reduce the use of material concrete constituents. Pezzi, et al. [2] examined the use of plastic material particle as aggregate in concrete indicated that added polymeric materials in fraction 610% in volume of cement matrix does not entail significant variation of mechanical properties of concrete. Shahrul, et. al. [6] discovered on how to replace aggregate with plastic waste. That investigation presented the Artificial Polyethylene Coarse Aggregate (APEA) were produced from waste plastic bags. The Polyethylene of plastic bag was heated at about 150°C for 10 to 15 minutes to be melted and hardened when it cooled down. The standard sizes every single heated Polyethylene adapted to the actual size of aggregate, i.e. 15-20mm. Each concrete block contained of 0%, 3%, 6%, and 9% of APEA as coarse aggregate substitution. The investigation [6] concluded that the 6% APEA more strength about 10% than the normal concrete.

Based on the investigation of Shahrul, et. al. [6] showed the APEA has a lack of bonding between artificial aggregate and cement matrix so, the strength of concrete decreased. Therefore, this study is motivated to improve the artificial aggregate of waste plastic APEA. The objective of this investigation was to increase the bonding ability of the available APEA [6] with the cement paste in concrete. Since the bonding between aggregate and cement paste is the critical important role to determine the mechanical properties of concrete [7] especially, its compressive strength. Furthermore, this modified aggregate is called MAPEA (Modified Artificial Polyethylene Aggregate). The MAPEA was produced from the APEA [6] which coated by glass dust on its surface. In experiment, the compressive strength of concrete contained 3%, 6%, 9%, and 12% of MAPEA were observed. The concrete with 3% of MAPEA was the highest compressive strength than others content. The concrete contained more than 3% MAPEA and APEA have no significant in strength. The microstructure views showed the micro-crack has found in matrix concrete that could propagate as cracking in concrete matrix. From those results, the concrete contained both MAPEA and APEA could not be more than 3% due to interfacial zone problem between artificial aggregate with cement paste. However, presents the MAPEA can improve the strength of concrete than APEA.

2. Materials and methods

2.1. MAPEA Production

Artificial Polyethylene Aggregate (APEA) is produced from waste plastic bags that were heated process at about 180°C for 20 minutes. The standard sizes of this artificial aggregate were range from 15 - 20 mm. Initially, the waste plastic bags are compressed and formed into the ball shape with diameter 30mm further, it would be shrink to the size 15-20 mm after heated (see Figure 1). MAPEA (Figure 2c) basically produced as APEA. Figure 2a shows the APEA initially was painted, then coated by glass dust (Figure 2b). The MAPEA was coated by the glass dust aims to improve its roughness, since the roughness of aggregate is play important role on mechanical properties of concrete [8]. In addition, the glass is another abundant waste materials which containing the Silica and expected to bond cement paste together.



(a) (b)

Figure 1. Artificial Polyethylene Aggregate (APEA): a) before heated and b) after heated

(a) (b) (c)

Figure 2. a) The APEA painted b) Coating of APEA with glass dust c) MAPEA

2.2. Concrete mix design

As recommended by the Department of Environment (DOE) [9], the concrete in this experiment is designed to achieve a compressive strength of 25 N/mm^2 on day 28. Besides, the production of all samples also based on normal concrete mixes design. Concrete mix designs are intended to produce a mixture that suitable to achieve the objectives strength. Fifty-four (54) concrete cubes containing APEA and MAPEA were tested to carry out each its strength. The experiment produced three batches mixes design. First batch was produced the specimens of normal concrete as a control. The second batch, the samples concrete contained 3%, 6%, 9%, and 12% of APEA were produced. The third batch was created the sample concrete contained 3%, 6%, 9%, and 12% of MAPEA.

2.3. Slump Test Setup

The consistency of fresh concrete is determined by the proper of water and materials mixed such as water, cement, sand and aggregate. This consistency is the standard traversed to produce a good concrete. Since the consistency of fresh concrete affect on the workability concrete, segregation, and bleeding further, influence the strength of concrete [10]. No exception for this experiment which provided the concrete contained the APEA and MAPEA. Therefore, this investigation adopted the BS EN 12350-2 [11] for testing fresh concrete by Slump test.

2.4. Compressive Strength Test Setup

This test is an objective of this investigation which the uniaxial load was applied on the specimens to carry out the compressive strength of APEA and MAPEA concrete cube with size 150m x 150mm x 150mm. This destructive concrete testing was accordance to BS 12390-3 [12]. The specimens was loaded continuously without shocked, which the constant rate in this investigation was 0.6 N/mm^2.s.

2.5. Scanning Electron Microscope (SEM)
Scanning Electron Microscopy (SEM) was used to analyze the microstructure of APEA and MAPEA concrete. The concrete sample sized 1cm diameter and 0.3 thickness prepared to conduct SEM test. Before the concrete sample entered to the machine, the sample required to be coated with Aurum (Au) as electrical conductive material for 20 minutes of all process coating in sputter coater machine. The coating aimed to avoid the microscope captured the bias or excess of reflected light.

3. Results and Discussions

3.1. Slump Test
Based on the observation during mixing and compacting of all samples concrete mixture, the result can be suggested that the concrete was not segregating and bleeding. Figure 3 shows the graph of height slump versus the percentage of APEA and MAPEA. The height slump values rises with the increasing percentage of APEA and MAPEA. From the graph shows the increasing height slump value both materials are similar. This indicates that present the APEA and MAPEA in concrete mixture for slump test are not significant. In this experiment, the increasing value was due to amount of artificial aggregate increased and the mixture more saturated [10]. However, all concrete samples were passed in the slump test, since the height slump does not exceed to 115 mm [11]. Furthermore, the concrete can be tested for compressive strength [12].

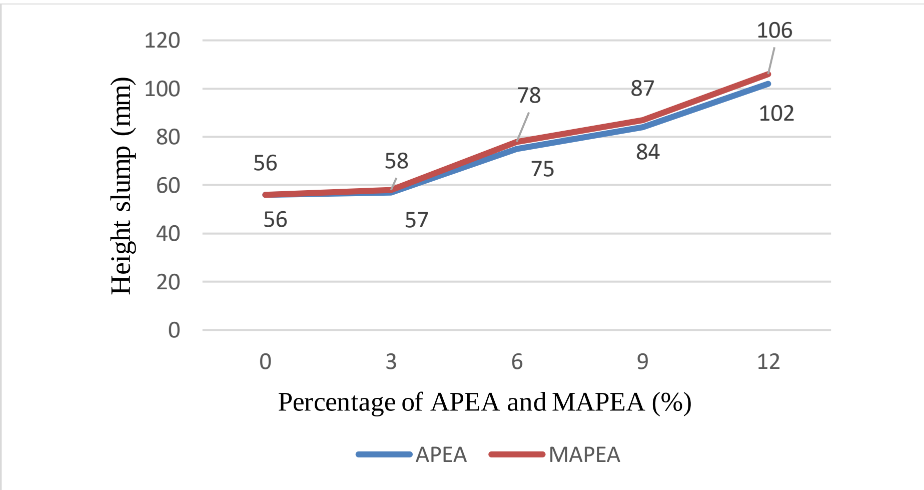


Figure 3. Result of Slump Test on fresh state APEA and MAPEA concrete.

3.2. Compressive Strength
Based on Figures 4 and 5, the graph shows that the concrete cube with 3% APEA and MAPEA have the highest compressive strength. Actually, the compressive strength of MAPEA and APEA concrete decreased as the percentage of APEA and MAPEA increased. The surface of MAPEA was made rougher to imitate the surface of normal aggregate, so that the compressive strength of MAPEA concrete was higher than APEA concrete. This is relate to interfacial zone between MAPEA and cement paste in matrix concrete [8]. Figure 4 shows all percentage of the samples at 14 curing days, the MAPEA concrete little higher than APEA concrete. However, when all samples at 28 curing days the MAPEA concrete decreased as increasing percentage of MAPEA. The MAPEA concrete was no significant with APEA concrete, even 12% MAPEA concrete was weaker than the 12% APEA concrete. This indicates the percentage of artificial aggregates such APEA and MAPEA should be not exceed to 3%, where the matrix of concrete will be disrupted by the presence of excess artificial aggregate at 28 age curing days

[13]. The excess artificial aggregate interfere the interfacial bonded during hydration of cement process in matrix concrete. Hsu, et. al. [14] reported that the micro-crack or shrinkage presumably occur in period of cement hydration process. This can be comprehended when an artificial aggregate make the bigger bond-crack in interfacial cement matrix. This phenomena can be cleared by using Scanning Electron Microscope (SEM) to observe the microstructure of concrete.

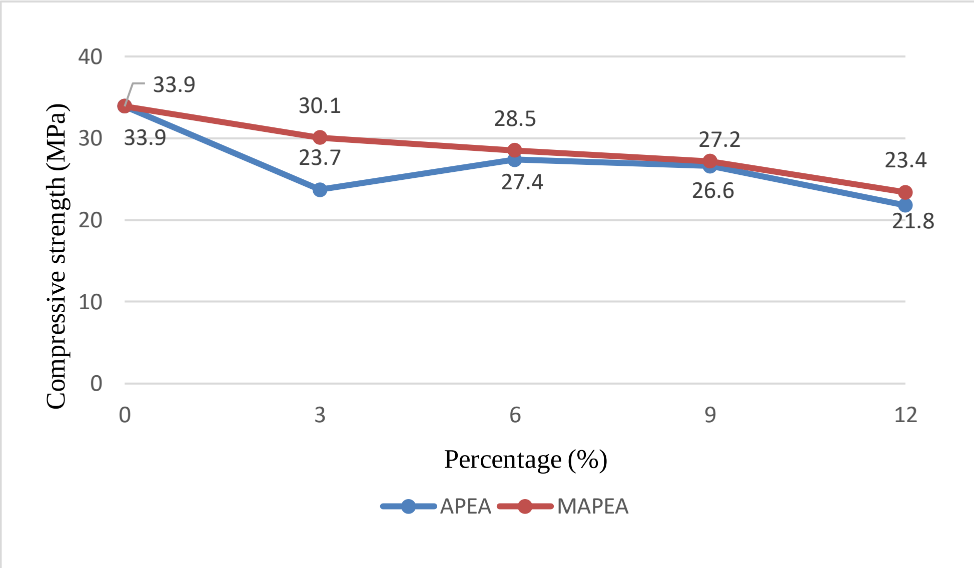


Figure 4. Compressive Strength of concrete at 14 days

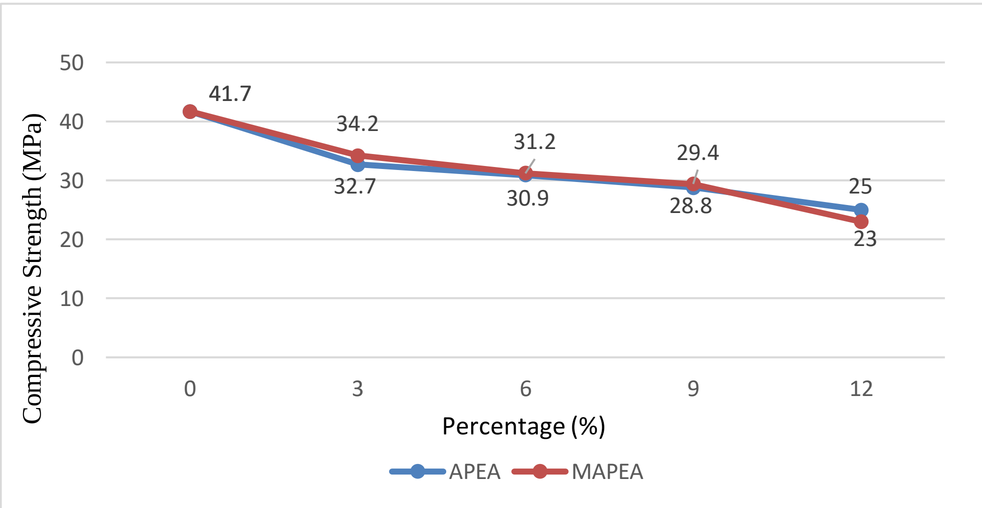


Figure 5. Compressive Strength of concrete at 28 days

Figure 6 presents the microstructures of APEA and MAPEA concrete. The APEA shows detached from the concrete and not bond well in cement paste (see Figure 6a). This is because of the smooth surface of APEA could not bond well with cement paste as well as normal aggregate. Therefore, the presence APEA in concrete accelerate cracking in matrix concrete. Meanwhile, the MAPEA "little" bond into concrete matrix (Figure 6b), the rough surface of MAPEA that imitate the surface of normal aggregate made it better bonded with cement paste. However, the MAPEA concrete created the micro-

IOP Conf. Series: Materials Science and Engineering **160** (2016) 012065 doi:10.1088/1757-899X/160/1/012065

crack between MAPEA and cement paste due to shrinkage presumably during cement hydration process [14, 15]. This observation, calculated that the micro cracks of concrete containing MAPEA ranging from 45 µm to 77 µm. Previous researchers [14, 15, 16] observed that the interfacial between coarse aggregate and cement paste is weakest bond in concrete. Micro crack initiates to propagate the crack in concrete further decreased the strength of concrete [17]. Actually, this micro-crack occur when the role of calcium hydroxide from the cement hydration subtracting the capacity of interfacial adhesive of cement paste [18]. In addition, the water absorption of MAPEA more 1.29% than normal aggregate, this is clearly the MAPEA subtracting the water in hydration process.

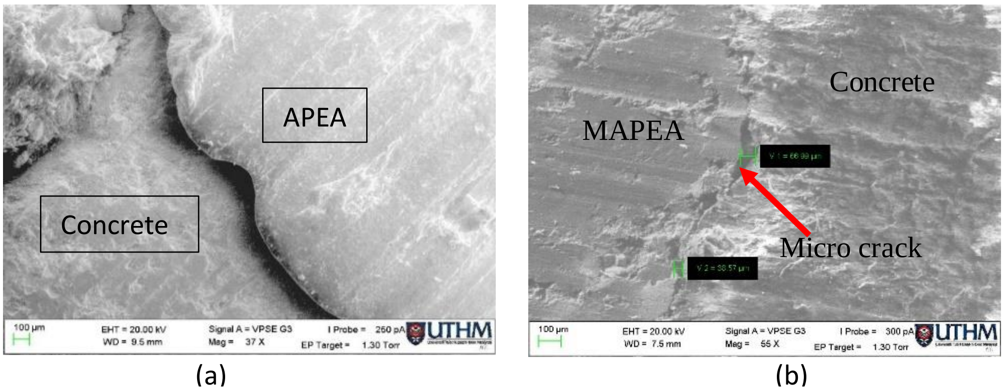


Figure 6. Microstructure images of a) APEA concrete and b) MAPEA concrete.

4. Conclusions

This experimental investigation on compressive strength of 0%, 3%, 6%, 9%, and 12% of APEA and MAPEA has been conducted. The concrete containing 3% MAPEA was highest compressive strength. Although the strength of MAPEA concrete under level normal concrete, this can be understood that the MAPEA concrete is a light weight aggregate concrete (LWAC). Therefore, MAPEA concrete contributes to improve the available APEA, which MAPEA has surface roughness to increase the bonding in matrix concrete and increased its strength.

Even though the presence MAPEA in concrete increased its strength, the difficulties on MAPEA concrete still found concerning interfacial zone between MAPEA and cement paste. However, this problem is not only occurs in MAPEA concrete but also at normal concrete with normal aggregate correspond to weakest area bonding in concrete between aggregate and cement paste due to loss of adhesive cement hydration. This investigation has reached the objective that modification of APEA surface to be MAPEA increased the strength of concrete compared to APEA concrete. In future investigation should be thought for subtracting this interfacial bonding problem with increased the tensile bonding of artificial aggregate.

Acknowledge
The authors wish to acknowledge with gratitude the facilities, staffing resources, and financial support provided by Centre of Research, Innovation, Commercialization and Consultancy Management Office (ORRIC), University of Tun Hussein Onn Malaysia.

References

[1] Davis M L and Cornwell D A 1998 *3rd Edition WCB, McGraw-Hill.*

[2] Pezzi L, De Lice P, Vuono D, Chiappetta F and Nastro A 2006 *Materials Science Forum, Trans Tech* **514**, 1753–1757.
[3] Jo B W, Park S K and Kim C H 2006 *ACI Structural Journal* **103** 219–225
[4] Hınıslıogˇlu S and Agˇar E 2004 *Materials Letters* **58** 267– 271
[5] Tam V W Y and Tam C M 2006 *Resources Conservation & Recycling* **47**, 209–221
[6] Mokhatar S N, Jaini Z M, Burhanudin M K, Jeni M L A, & Ismail M N N 2015 *InCIEC Springer Singapore* 691-701.
[7] Husem M 2003 *Materials Science and Engineering: A* ***363*****(1)**, 152-158.
[8] Rao G A and Prasad B R 2002 *Cement and Concrete Research* ***32*****(2)**, 253-257.
[9] Aginam C H, Umenwaliri S N, & Nwakire C 2013 *ARPN Journal of Engineering and Applied Sciences* ***8*****(6)**, 1-7.
[10] Hoshino M 1989 *Materials Journal* ***86*****(2)**, 185-190.
[11] BS EN 12350-2 2009 *Testing fresh concrete. Slump-test*.
[12] BS-EN-12390-3 2009 *Compressive Strength of Test Specimens.*
[13] Saikia N and de Brito J 2012 *Construction and Building Materials* ***34***, 385-401.
[14] Hsu T T, Slate F O, Sturman G M and Winter G 1963 In *Journal Proceedings* **60(2)**, 209-224.
[15] Slate F O and Olsefski S 1963 In *Journal Proceedings* **60(5)**, 575-588.
[16] Thomas T C and Slate F O 1963 In *Journal Proceedings* **60(4)**, 465-486.
[17] Perry C and Gillott J E 1977 *Cement and Concrete Research* ***7*****(5)**, 553-564.
[18] Marchese B 1983 *Cement and Concrete Research* ***13*****(3)**, 435-440.