Study of Fly Ash Plastic (FAPET) as alternative lightweight aggregate in concrete

K A Sambowo*, F Apriyanto, P Prihantono and R A Sumarsono

Department of Civil Engineering, Universitas Negeri Jakarta, Jl. Rawamangun Muka Jakarta Timur 13220, Indonesia

*kusnoadisambowo@unj.ac.id

Abstract. Plastic waste is identified as non-biodegradable material that is harmful to the environment. PET is one of the most well-known types of plastic used for food packaging that usually plastic waste be found in huge amounts. This paper takes advantage of PET plastic waste from the water drinking cup to be blended with fly ash to produce a lightweight aggregate called FAPET. All the properties of FAPET were significantly better than pumice as the control sample during the experiment such as water absorption, compressive strength and abrasion value of 0.5%, 17.4 MPa and 28.55% respectively. FAPET was derived from the double blending process of PET with fly ash with the composition of PET and fly ash was 1:3. The experiment conducted was partial until the full replacement of pumice as a lightweight aggregate with FAPET to establish waste-based lightweight concrete. Modulus of elasticity and compressive strength resulted from 100% replacement using FAPET were 31,706 MPa and 23,64 MPa that equalled to normal concrete strength. The utilization of FAPET is concluded to be successful as an alternative lightweight aggregate for structural use of lightweight concrete.

1. Introduction
Lightweight concrete can be acquired by eliminating the fine aggregate, inserting air/bubble, or utilizing lightweight aggregate in the concrete mixture. The availability of lightweight aggregate in the nature is limited as we can notice pumice as one of it. Pumice is a natural lightweight (sponge-like) aggregate shaped throughout the fast cooling and solidification of volcanic matter (molten lava) which is generally rhyolitic in conformation. The porous structure of pumice is formed by bubbles formation or trickling millions of tiny air voids when gases molten lava are tricked during cooling [1].

Recent studies for switching the natural lightweight aggregate with some other alternatives of artificial lightweight aggregate are widely developed. Some light by-product materials are tested for their eligibility as the replacement of natural lightweight aggregate. Plastic is one of the choice due to its common use in daily basis. Moreover, the use of plastic has exponentially increased the threat of the sustainability of our earth in the past few years. PET (polyethylene terephthalate) is one of the derivations of plastic which is often engaged in many food packaging. The characteristics of PET plastic is stiff and strong which met the requirement of aggregate property in concrete.

Previously, the employment of PET plastic as aggregate in concrete shown the same behavior as normal concrete, though incorporating PET as aggregate significantly lowered the strength performance such as compression and flexure due the shape of the PET aggregate [2]. The sleek surface of the PET aggregate was found out to be the problem of low strength of concrete even though the compressive
strength of PET was excellent. This paper will work on from the weakness of PET-aggregate shape formerly, so that the surface of PET plastic can be as good as coarse or fine aggregate in bonding with cement.

Next, the idea of creating coarse surface of the PET aggregate will be including fly ash as the supplementary cementitious material which is expected to create better bonding with cement. Nowadays the use of fly ash in concrete has spread to be accepted and standardized in almost every country in the world. The contribution of fly ash is giving rheology enhancement and long term performance, but at the cost of early-age strength [3]. Furthermore, research on structural concrete has established that appropriate lightweight aggregates do not have deficiencies in performance compared to concrete made with natural aggregates. As the need increases for alternatives of artificial lightweight concrete, there are chances to capitalize the exist resources, for which there is currently no accepted use in their present form such as plastic waste [4].

2. Material and methods
Comparing the strength of coarse aggregate using natural lightweight aggregate of pumice and artificial lightweight aggregate of fly ash plastic is explained in this section. The development of artificial lightweight aggregate has introduced the thermal treatment for example artificial ceramsite made from clay or sintered fly ash which is amorphous and rich in SiO₂ and Al₂O₃ [5]. In this paper, the percentage of pumice replacement is 0 until 100% thus the eligibility of proposed artificial aggregate can be measured. Utilization of PET and fly ash as artificial aggregate regarding the compression performance is the focus of discussion. Previous study, the use of pumice aggregate related to the strength of the lightweight concrete was determined by the ratio of pumice to cement. The ratio of 10:1 resulted the heavy duty specimen block of strength durability, however 20:1 would work well for load bearing purposes [6].

2.1. Fly ash plastic (FAPET) lightweight aggregate
Prior, the preparation of the making FAPET aggregate was blending the transparent PET plastic waste and fly ash with the proportion of 3:1. Melting the PET into liquid state was the next step, the fly ash was input to the liquid PET continued by stirring until they were uniform. Let it dry and hardened, then crushed it into small size then sieved it. The FAPET aggregate used for the concrete mixture was passed the sieve No. 4 (4.75 mm) which met the requirement of coarse aggregate.

The preliminary test of both aggregates perceives in table 1, where all the properties tested was match the coarse aggregate tested. Exceptionally, the abrasion value of pumice was missed, however the abrasion value of pumice from previous researches was around 35%. The weakness of pumice is high absorption due to many voids that causes lower specific gravity even when we compare with FAPET. The highlight of FAPET properties are water content, compressive strength, and abrasion of its individual, those values are excellent as coarse aggregate requirements, yet lightweight.

| Properties            | Pumice | FAPET   |
|-----------------------|--------|---------|
| Water content         | 0.95%  | 0.075%  |
| SSD specific gravity  | 1.04 gr/cm³ | 1.42 gr/cm³ |
| Absorption            | 51.45% | 0.5%    |
| Fineness modulus      | 7.31   | 7.04    |
| Compressive strength  | 3 MPa  | 17.4 MPa|
| Abrasion              | NT     | 28.55%  |

Note: NT = Not Tested
of PET was in terms of plastic flakes so that the abrasion value was not good enough as coarse aggregate [2].

2.2. Methodology
The mix design of lightweight concrete based on [7] where the water cement ratio of the concrete mixture was 0.27 in order to reach the minimum target compressive strength of 17.24 MPa for structural application. Pumice replacement applied was 0%, 25%, 50%, 75% and 100% to the FAPET aggregate. The requirement of concrete density was between 1400 kg/m$^3$ and 1800 kg/m$^3$. Concrete mould used was cylinder type with the height of 300 mm and diameter of 150 mm so that the result of compressive strength did not need any shape conversion revision.

During the mixing process, all the steps were initially the same as normal concrete mixing procedure. There were no significant obstacles during mixing and moulding, including compaction process. Curing procedure by soaking the samples into the water was carefully observed for 28 days.

3. Results and discussion
Structural lightweight concrete varies in definition in certain parts of the world, however it usually refers to the concrete with oven dry density of no greater than 2000 kg/m$^3$ [8]. The density of all specimens is below the criteria despite 100% use of FAPET reaches almost 1900 kg/m$^3$. As the specific gravity of FAPET are higher than pumice, but FAPET shows satisfying results.

Monitoring the slump value which has the tendency of rising as the pumice is eliminated, we could predict the high increment of slump due to very minimum absorption of the FAPET. There is almost zero water absorbed by FAPET which adds the workability of fresh concrete mixture. In another case of cementitious supplementary material, the addition of cementitious material had negative influence on the workability of concrete [9]. However, the addition of cementitious supplementary material applied in this research is blending the melted plastic with the fly ash so that it does not create direct reaction with cement particularly. In general, low compressive strength affects from the escalation of slump value (figure 1).

![Figure 1](image_url). Slump, density, compressive strength and modulus of elasticity values
Further discussion of mechanical behavior of the lightweight concrete samples are the compression behavior and modulus of elasticity. The most important practical factor to decide the strength behavior concrete is the water-cement ratio, but the underlying parameter is the number and size of pores in the hardened cement paste [10]. It is proven that the water-cement ratio got from the mix design is suitable to produce good quality of FAPET lightweight concrete. Besides, higher slump value does not restrict the compression behavior of FAPET concrete specimen to reach better. Inline with the compressive strength, the modulus of elasticity is greater as incorporating FAPET as the lightweight aggregate. Thus, the stiffness of FAPET concrete shows more decent ductility of a lightweight concrete which is compatible for structural needs.

4. Conclusion
Referring to all the experimentation results and explanations, we may conclude the followings:

- FAPET successfully improves the performance of lightweight concrete for structural uses both on strength and workability. However, the crack pattern of this specimens needs further investigation.
- In order to gain better lightweight FAPET aggregate, several approaches could be taken such as production process (introduce the molten lava process like pumice), heating and melting PET process and proportion study of fly ash and PET.

References
[1] Rashad A M 2019 A short manual on natural pumice as a lightweight aggregate J. Build. Eng. 25 100802
[2] Hameed M and Ahmed B A 2019 Employment the plastic waste to produce the light weight concrete Energy Procedia 157 30–8
[3] Courard L, He H, Michel F, Snellings R and Belie N De 2012 Supplementary Cementitious Materials for Concrete: Characterization Needs Material Research Society Symposium vol 1488
[4] Clarke J L 2005 Structural Lightweight Aggregate Concrete (Berkshire: Blackie Academic and Professional)
[5] Huang H, Yuan Y, Zhang W, Liu B, Viani A and Mácová P 2019 Microstructure investigation of the interface between lightweight concrete and normal-weight concrete Mater. Today Commun. 21 100640
[6] Gu L 2008 The effects of pumice aggregate / cement ratios on the low-strength concrete properties Constr. Build. Mater. 22 721–8
[7] Umum D P 2002 SNI 03-3449-2002 tentang Tata cara pencemaran campuran beton ringan dengan agregat ringan (Bandung)
[8] Newman J and Choo B S 2003 Advanced Concrete Technology - Processes (Burlington: Elsevier Ltd)
[9] Xie J, Liu J, Liu F, Wang J and Huang P 2019 Investigation of a new lightweight green concrete containing sludge ceramics and recycled fine aggregates J. Clean. Prod. 235 1240–54
[10] Neville A M and Brooks J J 2010 Concrete Technology (Essex: Prentice Hall)