The Role of POFA and Recycled Plastic in Enhancing Concrete Properties

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Abstract. The experimental work of waste utilization for Grade 30 concrete incorporating Palm Oil Fuel Ash (POFA) and treated Polyethylene Terephthalate (PET) being presented in this paper. POFA is an agricultural waste from palm oil industry that creates uncontrolled landfill disposal, contain high silica-alumina which act as a good pozzolanic material as binder similar to cement. 45 cube specimen size 100 x 100 x 100 mm were prepared with 2 mol, 4 mol, 6 mol and 8 mol of Sulphuric Acid to treat PET. The objectives were to evaluate the workability and performance of POFA and treated PET concrete through slump test and compression test at 7, 14 and 28 days. As the findings, treated PET with 8 mol Sulphuric Acid and 5% POFA concrete significantly improves consistency compared to the control specimen. This resulted from the liquidation technique applied to POFA during the concrete mixing process that functions as a liquid lubricant which can easily blend with cement component. Moreover, 5% POFA and 8 mol treated PET concrete shows strength increment due to the combination effect between raw POFA that act as filler and PET act as fiber reinforcement to help the concrete.

1. Introduction
Construction industry plays a significant contribution for national socio-economic development by building structure and infrastructure to our country. For construction industry, concrete is among the most vital and frequently utilized material in the world which being part of the development since then. One of the most important material in concrete is Portland cement that functions as binder when it reacts with water, used to bind coarse aggregates and fine aggregates together in concrete mix proportion. However, the price of Portland cement is expensive, and the price keep increasing throughout the year. Moreover, the emergence of cement production creates negative effect by releasing toxic gases emissions such as CO₂ to our environment. Other than ecological and economic issue, another primary cause such as technological issue contributes the expanding interest in utilizing agricultural or industrial waste in construction materials. It is essential to explore other raw material
that low-cost and sustainable as partial cement substitution but at the same time can improve material performance.

Researchers had to investigate any beneficial alternatives available to sustain the concrete industry by opting waste or by-product while maintaining substantial effects on concrete properties, especially in the later age. Apart from rice husk ash, fly ash, waste paper sludge ash, slag and silica fume that have been widely studied in replacing cement, new material to improve concrete properties has been studied recently is green waste from palm oil industry. Back in 1960, oil palm tree plantation was firstly started with 54,000 ha and it keeps increasing each year and latest has recorded in year 2019, the plantation had expanded to 5.90 million hectares [1]. As a result of this industry development, the solid waste generated from palm oil such as palm oil clinker (POC), fibres, empty fruit bunches and palm kernel shell also increased [1-2]. According to Kanadasan and Razak [1-2], POFA was produced from the burning of these solid wastes during palm oil extraction process. Ismail et al. [3] stated that chemical composition of POFA contains a large amount of silica and that has high potential to be used as a cement replacement, besides for agriculture purpose. Moreover, the usage of POFA can exhibit cost reduction of producing concrete which gives great advantage to construction industry in planning construction projects with much cheaper budget [3-4].

Besides POFA, another waste that has been expanding in time is Polyethylene Terephthalate (PET), also known as plastics. PET is one of the most common consumer plastics used in the world especially for manufacturing beverage containers and other consumer goods, mostly for single usage. The production of PET exceeds 6.7 million tons/year and has been dramatically increasing in the Asian region due to recent increasing demands [5]. These current situation is challenging in every country in the world because will lead to another ecological issue similar to POFA such as landfill disposal and unfortunately will also give impact as they pollute oceans and waterways too if people hesitate to get involved in recycling concept to sustain our environment [6-10]. The recycling concept can reduce the problem of the accumulation of plastic waste, and one of the possible ways of recycling is utilizing these wastes in concrete construction in the form of construction material as replacement of sand or gravel [11]. Other researchers have found that PET is potentially act as fiber in concrete production and showed significant strength improvement for the concrete [11-12]. Therefore, these valuable findings have been further explored in this study by determining the potential combination effect of POFA and treated PET inclusion in the Grade 30 concrete in term of workability and performance using liquidation technique.

2. Materials and Method

Raw POFA originated from Palm Oil Factory in Nibong Tebal, Pulau Pinang and was sieved to 212 µm particle size. The concrete was designed for Grade 30 with constant w/b of 0.54. POFA was used as partial cement replacement with 5% replacement level and using liquidation technique before the mixing process [13]. The ratio is 1kg of water required in concrete mix: 200ml of water need to dilute the POFA powder (1kg water: 200ml for dilution) [13].

PET from drinking water bottles were obtained randomly in Universiti Teknologi MARA, Cawangan Pulau Pinang and were cut into 10 x 10 mm in size. PET was treated using Sulphuric Acid of 4 different mol which were 2 mol, 4 mol, 6 mol and 8 mol to determine the optimum mol that can contribute to the concrete consistency and performance. Slump test was conducted for fresh concrete properties to analyze on the workability mixes. Total 45 cube specimens size 100 x 100 x 100 mm were produced, which designed to evaluate on its performance by conducting compressive strength test at day 7, 14 and 28 of curing age. Then, the result was compared with control specimen which is Ordinary Portland Cement (OPC). The castings of the concrete, fresh and hardened testing tests were conducted at Concrete Laboratory, Universiti Teknologi MARA, Cawangan Pulau Pinang. Figure 1 below shows POFA and treated PET that being used in this study.
Concrete mix designation OPC indicated Ordinary Portland Cement or control specimen, 5PP2 indicated 5% POFA and 2 mol treated PET concrete, 5PP4 indicated 5% POFA and 4 mol treated PET concrete, 5PP6 indicated 5% POFA and 6 mol treated PET concrete and 5PP8 indicated 5% POFA and 8 mol. Table 1 below shows the concrete mix proportion for this study.

Table 1. Concrete mix proportion

| Mix Designation | Cement (kg/m²) | POFA (kg/m³) | Treated PET (kg/m³) | Water (kg/m³) | Fine aggregate (kg/m³) | Coarse aggregate (kg/m³) |
|-----------------|----------------|--------------|---------------------|---------------|------------------------|-------------------------|
| OPC             | 380            | -            | -                   | 205           | 680                    | 1155                    |
| 5PP2            | 360            | 20           | 20                  | (41 – mix with POFA) | 205                    | 680                     | 1155                    |
| 5PP4            | 360            | 20           | 20                  | (41 – mix with POFA) | 205                    | 680                     | 1155                    |
| 5PP6            | 360            | 20           | 20                  | (41 – mix with POFA) | 205                    | 680                     | 1155                    |
| 5PP8            | 360            | 20           | 20                  | (41 – mix with POFA) | 205                    | 680                     | 1155                    |

3. Result and Discussion
In this study the discussion of the findings was divided into two sections; consistency for fresh concrete and hardened concrete performance. The result and discussion are as follows.

3.1. Evaluation of POFA and treated PET effect on concrete workability
Figure 2 shows the workability effect of POFA concrete in terms of slump test evaluation. In general, the inclusion of POFA and increase the molarity of PET gradually improves the slump properties of concrete. This is confirmed by the highest slump is recorded by mix 5PP8 and followed by 5PP6, 5PPE, 5PP2 and OPC with 166 mm, 155 mm, 145 mm, 140 mm and 138 mm respectively. The enhancement in slump properties is believed from the action of POFA as filler and supplementary cementitious materials with the aid of PET which acting as reinforcement. The enhancement in slump properties is dominantly contribute by POFA which initial at early age acts as filler in densifying the fresh properties of concrete. Based on previous findings, the surface and shape of POFA which is rounded is the main reason of the enhancement in slump. The rounded shape of POFA performs ball bearing effect which ease the movement between the particle of POFA with cement. Apart from that,
the role of treated PET also helps to improves the workability by providing a lubricant between cement and POFA and eliminates the chance of segregation between concrete particles.

![Figure 2. Result of Workability](image)

3.2. Evaluation of POFA and treated PET effect on compressive strength

Figure 3 portrays the compressive strength of POFA and PET in concrete. Generally, the inclusion of POFA and PET in concrete shows a significant effect in enhancing the compressive strength of concrete at every age of testing. At day 7, the highest compressive strength is marked by 5PP2 mix with 28 MPa and followed by 5PP4 mix with 26 MPa, 5PP6 mix with 25 MPa, 5PP8 mix with 24 MPa and OPC with 23 MPa respectively.

![Figure 3. Compressive Strength of POFA/PET in concrete](image)

The strength enhancement is originated from finer particles of POFA which acts as filler. The first action of POFA at early ages is filling the void between cement and then creating the pozzolanic reaction. However, at day 14, the highest compressive strength is recorded by mix 5PP6 with 39 MPa and followed by 5PP2, 5PP4, 5PP8 and OPC at 32 MPa, 31 MPa, 31 MPa and 26 MPa in strength. Possible explanation to this matter is the action of PET at later ages which creates a better bonding effect with concrete particles. Moreover, the action of POFA gradually creates pozzolanic action which also contribute to the strength of concrete. The continuous effect from pozzolanic action combined well with cement and the action is optimally recorded by PET treated at 6 mol. Apart from
that, the treated PET with Sulphuric Acid, refine the texture of PET to become stiffer and surface of PET is refined which contributes to the good bonding effect with cement particles. The action of strength enhancement of POFA and PET concrete can be seen at day 28 days. The highest compressive strength is recorded by mix 5PP8 and followed by mix 5PP6, 5PP2, 5PP4 and OPC with 51 MPa, 48 MPa, 46 MPa, 42 MPa and 32 MPa respectively. The optimum effect performs by 5PP8 mix is contributes by continuous pozzolanic reaction from POFA and the role of PET as fiber which enhancing the bonding effect with cement particles. The role of Sulphuric Acid at high molarity which is 8 mol proves to stiffen the PET structure and performs a good fiber material. From this a conclusion can be made from the action of POFA and PET in concrete will creates three phases in strength enhancement. First the filler effect at early ages. Second, pozzolanic reaction by combining with cement and transforming the calcium hydroxide into active pozzolan. Finally the role of PET which is acts as fiber that improves the bonding effect with cement.

4. Conclusion
In this study, POFA and treated PET were incorporated into Grade 30 concrete to investigate the changes in workability and performance. Following conclusions can be drawn as listed below:

1. The slump test value result for 5% POFA with 8 mol treated PET indicated as the highest value compared other mol of Sulphuric Acid and OPC.
2. The inclusion of 5% partial replacement of POFA with 8 mol treated PET increased the compressive strength and this combination indicated the highest value compare to others and this can be the optimal percentage and mol in concrete.

POFA can be utilized as replacement for cement up to certain percentage level in the concrete production. Based on the results in this study, the following research recommendations were stated below for improvement of the study so that future researchers can achieve better findings:

1. Investigation of POFA effect on different percentage as cement replacement and work in combination with treated PET The amount percentage of POFA between 6% to 10% upward need to be studied so that the strength of concrete decrease as the amount of POFA increase can be proved.
2. Investigation of higher fineness POFA effect to evaluate optimum percentage of POFA for future study because it had been proved by some researchers that higher fineness of POFA increase the strength of concrete and increase the curing age of specimen to evaluate the performance of the concrete of certain desired curing age.
3. The mol of Sulphuric Acid for treating PET above 8 mol need to be studied further as this study result proved that different mol of Sulphuric Acid affect the concrete strength significantly.

5. References

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