Incorporation of Eco Process Pozzolan (EPP) as Partial Cement Replacement and Superplasticisers in Concrete

J H Kho

Civil and Structural Engineering Programme, Faculty of Engineering, Universiti Teknologi Brunei, BE 1410, Brunei Darussalam

Abstract. Eco Process Pozzolan (ePP) is obtained from the calcination of Spent Bleaching Earth (SBE) originating from the by-product of manufacture of edible oils. Studies have shown that ePP has cementitious properties and can be utilised as partial cement replacement in concrete. The limitations of ePP as partial cement replacement includes a decrease in concrete consistence, or workability. Superplasticisers are becoming commonly used in concreting works for increasing concrete workability; however, due to its chemical nature, may lead to possible side-reactions, especially when used with a new alternative material. This study focuses on the use of superplasticisers in concrete incorporated with ePP as partial cement replacement, and the resulting properties of the concrete. Concrete mixes include mixes using 100% ordinary Portland cement (i.e. 0% ePP), and mixes with ePP at 20% replacement level (i.e. 80% OPC), at 0.3 and 0.5 water to cement ratios. Three different types of superplasticisers were used, at various dosages in which one of them (polyethene-based) produces the best result. Slump tests and compressive strength tests were done at concrete ages of 7, 28, 56 and 91 days. The results show that utilisation of superplasticisers improved concrete workability and strength, regardless of the type of superplasticiser used, leading to easier compaction. The compressive strengths at long-term ages continually increases and were almost comparable to concrete using 100% OPC.

1. Introduction

1.1 Background

Cementing materials has been widely used for centuries for construction of various structures. Concrete is very vital in the construction industry especially starting the 19th century utilized up to an estimated 10,000 million tons yearly [1]. It is man-made, durable, resistant to most exposure, require minimal maintenance and therefore economical. However, production for 1 ton of Portland cement generates almost 1 ton of CO₂ in total [1]. 1 kg of cement produces about 800g of CO₂ in Type 1 cement that also emits SO₂ and NOₓ from 1.1 to 3.4g [1]. Therefore, it has its environmental effects. Spent Bleaching Earth (SBE) is an industrial by-product from the refining process of bleaching earth from manufacturing of edible oils. There is an estimation of approximately 600,000 million tons of bleaching earths used globally produces about 60 million tons of oil [2] and it was reported that in 2014, 1 to 2 million tons of SBE was produced globally containing 25-40% of oil and other contaminants. It usually ends up in landfills which can impact the environment negatively which can be hazardous i.e. highly flammable. Hence a sustainable option was created that is to further process and calcine SBE at high temperatures into Eco Process Pozzolan (ePP) and SBE oil.
SBE comprises of mainly bleaching clay and residual oil. An SBE sample was tested to a calorific value of 15.8J/g with ash content around 55%. After calcination at 550°C for 4 hours, the resulting ash satisfied the Kenya Standard chemical composition requirements for pozzolans [3]. Furthermore, it is also stated from another article that the total oil content from 10g of SBE was extracted via heating at high temperatures of 1000°C until no further sample weight loss, the average oil content was later calculated to be 24% [4].

Eco Process Pozzolan (ePP) is one of the pozzolanic materials with similar cementitious properties which can be used as a partial replacement of cement in the making of concrete, contributing to a healthier environment which also saves material costs. Its only limitation is found to be the workability/consistence which is important for hot climate countries like Brunei. One of the main reasons for this study is to understand and know more of the possibilities of EPP as there is lack of research on this pozzolan.

According to Sharom’s research, he tested ePP at 20%, 25%, 30%, 35% and 40% with 100% OPC as control mix to determine its workability, compressive strength, water absorption and porosity in which he concluded use of less than 30% of ePP produces better performance [5]. As for the experimental tests done by previous studies from Universiti Teknologi Brunei (UTB); Jarjusey[6] and Noordin[7], it was concluded 20% ePP, 80% OPC to be the most suitable choice (i.e. found to be most optimum) amongst 15%, 20%, 30% and 40% as it is found to produce most optimum results in their lab experiments. For this reason, 20% ePP with 80% OPC is selected for this study to further discover and enhance the mix.

Up to the early 1930s, concrete was known for comprising of cement, water and aggregates. And in the 1940s, accidental discovery of chemical admixtures has led to the rapid development of chemical products and admixtures for enhancing the properties of concrete like workability, early strength and setting time. Later in the 1960s, superplasticisers were evolved and introduced which include the commonly used poly-b-naphthalene sulfonates (PNS) and poly melamine sulfonates (PMS) [8]. Lignosulfonate-based air-entraining water reducing agents were the first generation of superplasticizers, which is then followed by-naphthalene sulfonate-based products and finally the recently used polycarboxylate-based products which possesses very sophisticated molecules which helps further enhance the properties [9]. According to the researchers, it has been concluded that the slump loss is highly effective using superplasticisers [8] and the cohesiveness of concrete are improved with superplasticisers but reduces with high dosages [10].

1.2 Experimental Methodology

First; to prepare and calculate the design mixes of water cement ratios of 0.3 and 0.5 of moulds 100x100x100mm in accordance to the DoE guidelines and British Standards:

- 100% OPC
- 80% OPC with 20% ePP
- 80% OPC with 20% ePP + each type of superplasticisers

It is then followed by slump tests to test workability of concrete’s fresh state in accordance to BS1881:108. Afterwards, compressive strength tests during concrete’s hardened state at days 7, 28, 56 and 91 after curing. Then, the comparisons between the design mixes of OPC, OPC+ePP and OPC+ePP with superplasticisers. Superplasticizers; SP1 (naphthalene sulphonate based), SP2 (retarding superplasticizer) and SP3 (polycarboxylate based) were used.

Cubes of 100mm dimensions were used for determining the compressive strengths of the concrete in accordance to BS EN 12390-3:2002. Relevant studies by Duraman [11] and Zainsalehen [12] have shown that 100mm cubes are more optimally preferred for laboratory studies of this nature as compared to 150mm cubes, and provides a good representation of the properties of the concrete, and hence were utilised.

Water cement ratios 0.3 and 0.5 were chosen because 0.5 is the typically used and preferred option for the ideal concrete mix and results and in this project, it was desired to test and see if it can be further be utilised to work with w/c 0.3 as water requirement is reduced and much higher strength is expected.
Meanwhile up to 91 days of curing and compressive strength were tested to observe the mix with the pozzolan (ePP) used for its long term effects and whether it will continue to increase its strength with long-term aging. Several sets of experimental mixes were conducted in separately and in different times so they are to be classified and referred to as Mix Set 1, Mix Set 2, Mix Set 3 and Mix Set 4 as shown in Table 1. Mixture names will be summarised i.e. 20%epp instead of 20%epp 80%OPC.

| No. | Mix Set 1       | Mix Set 2       | Mix Set 3 of w/c 0.3 | Mix Set 4 of w/c 0.5 |
|-----|-----------------|-----------------|---------------------|---------------------|
| 1   | 20% ePP(0.3% SP1) | 100% OPC       | 100% OPC            | 100% OPC            |
| 2   | 20% ePP(0.3% SP2) | 20% ePP       | 20% ePP             | 20% ePP             |
| 3   | 20% ePP(0.3% SP3) | 20% ePP(0.5% SP1) | 20% ePP(0.3% SP1) | 20% ePP(0.3% SP1) |
| 4   | 20% ePP(0.5% SP2) | 20% ePP(0.5% SP1) | 20% ePP(0.5% SP1) | 20% ePP(0.5% SP1) |
| 5   | 20% ePP(0.5% SP3) | 20% ePP(0.3% SP2) | 20% ePP(0.3% SP2) | 20% ePP(0.3% SP2) |
| 6   |                 | 20% ePP(0.5% SP2) | 20% ePP(0.5% SP2) |                     |
| 7   |                 | 20% ePP(0.3% SP3) | 20% ePP(0.3% SP3) |                     |
| 8   |                 | 20% ePP(0.5% SP3) | 20% ePP(0.5% SP3) |                     |

### 2. Results and Discussion

#### 2.1 Slump Test

The slump test as mentioned previously is performed to determine the workability of concrete mix. Tables 2, 3, 4 and 5 will demonstrate the slump results for all 4 sets of mixes done.

| Batch | Design Mix | SP [kg/m³] | Avg. Slump [mm] |
|-------|------------|------------|-----------------|
| 1     | 20% ePP(SP1) | 1.35       | 100             |
| 2     | 20% ePP(SP2) | 1.35       | 65              |
| 3     | 20% ePP(SP3) | 1.35       | 125             |

| Batch | Design Mix | SP [kg/m³] | Avg. Slump [mm] |
|-------|------------|------------|-----------------|
| 1     | 100% OPC   | -          | 140             |
| 2     | 20% ePP    | -          | 100             |
| 3     | 20% ePP(SP1)| 2.25       | 195             |
| 4     | 20% ePP(SP2)| 2.25       | 135             |
| 5     | 20% ePP(SP3)| 2.25       | Segregation     |
Table 4. Mix Set 3 of w/c0.3’s slump results.

| Batch | Design Mix [w/c 0.3] | SP [kg/m³] | Avg. Slump [mm] |
|-------|-----------------------|------------|-----------------|
| 1     | 100% OPC              | -          | 8               |
| 2     | 20% ePP               | -          | 0               |
| 3     | 20% ePP+0.3% SP1      | 2.1        | 10              |
| 4     | 20% ePP+0.5% SP1      | 3.5        | 12              |
| 5     | 20% ePP+0.3% SP2      | 2.1        | 8               |
| 6     | 20% ePP+0.5% SP2      | 3.5        | 10              |
| 7     | 20% ePP+0.3% SP3      | 2.1        | 13              |
| 8     | 20% ePP+0.5% SP3      | 3.5        | 16              |

Table 5. Mix Set 4 of w/c 0.5’s slump results.

| Batch | Design Mix [w/c 0.5] | SP [kg/m³] | Avg. Slump [mm] |
|-------|----------------------|------------|-----------------|
| 1     | 100% OPC             | -          | 30              |
| 2     | 20% ePP              | -          | 20              |
| 3     | 20% ePP+0.3% SP1     | 1.26       | 38              |
| 4     | 20% ePP+0.5% SP1     | 2.1        | 53              |
| 5     | 20% ePP+0.3% SP2     | 1.26       | 33              |
| 6     | 20% ePP+0.5% SP2     | 2.1        | 53              |
| 7     | 20% ePP+0.3% SP3     | 1.26       | 51              |
| 8     | 20% ePP+0.5% SP3     | 2.1        | 170 (fail)      |

Figure 1. Slump test results at 0.5w/c on Mix Sets 1 and 2.
Figure 2. Slump Test Results at 0.3w/c (Mix Set 3) and 0.5w/c (Mix Set 4).

Figure 1 demonstrates the comparison between the different design mixes. From the design mixes conducted, the workability results for individual types of superplasticisers can be compared between Mix Sets 1 and 2. As for Figure 2; it shows the average slump results obtained between Mix Sets 3 and 4 of w/c 0.3 and w/c 0.5 and it is found to produce similar results in terms of the same mixes i.e. workability of 100% OPC performs better than 20% ePP without superplasticisers. 20% ePP with 0.5% SP3 for w/c 0.5 is not displayed as it is 170mm, difference is too high. Slump of w/c 0.3 conducted tend to appear dry and stiff especially on mix without superplasticisers contributing to very small slump values.

With the increase of superplasticisers from 0.3% to 0.5%; the slump height increases as shown in Figures 1 and 2. SP3 is a high grade superplasticiser which can achieve required workability with very small percentage. For this reason, as seen in Figure 1; it has highest slump height in Mix Set 1 and by Mix Set 2 at 0.5%, it was already bleeding and segregated during mixing hence it couldn’t proceed to the next steps.

Whereas for Figure 2, it can be seen from Design Mix (w/c 0.3) that SP3 boosts the workability of mix with ePP the most although it is not shown under Design Mix (w/c 0.5). This is because it was showing signs of segregating during mixing and the slump has reached 170mm which is way beyond the targeted slump of 30-60mm. Nevertheless, the mixture was later casted into molds and tested for its strength like the others. The incorporation of ePP as partial cement replacement reduces the workability due to its properties of low density and high surface area; hence as shown in Figures 1 and 2, the inclusion of small amount of superplasticisers can enhance the workability much higher as mentioned in previous study by Kovler. Furthermore; the performance of the 3 superplasticisers can be observed in an orderly manner from the least to most workability when incorporated into mix – SP2, SP1, SP3.
2.2 Compressive Strength Test
For Mix Sets 1 and 2, cubes of 0.5 w/c ratio were tested for their average compressive strength on days 7 and 28 which is shown in Tables 6 and 7 whereas for Mix Sets 3 and 4, cube samples of 0.3 and 0.5 w/c ratios were tested for 7, 28, 56 and 91 days which is shown in Tables 8 and 9.

Table 6. Mix Set 1’s average compressive strength results.

| Batch | Design Mix | SP [kg/m³] | Avg. Comp. Strength [N/mm²] |
|-------|------------|------------|-----------------------------|
| 1     | 20% ePP(SP1) | 1.35       | 31.56 44.56 |
| 2     | 20% ePP(SP2) | 1.35       | 35.44 47.56 |
| 3     | 20% ePP(SP3) | 1.35       | 34.22 48.67 |

Figure 3. Mix Set 1 of 0.3% superplasticiser

Table 7. Mix Set 2’s average compressive strength results.

| Batch | Design Mix | SP [kg/m³] | Avg. Comp. Strength [N/mm²] |
|-------|------------|------------|-----------------------------|
| 1     | 100% OPC   | -          | 38.67 48.00 |
| 2     | 20% ePP    | -          | 31.78 46.45 |
| 3     | 20% ePP(SP1) | 2.25       | 31.67 46.22 |
| 4     | 20% ePP(SP2) | 2.25       | 35.00 48.56 |
| 5     | 20% ePP(SP3) | 2.25       | N.A N.A |

Figure 4. Mix Set 2 of 0.5% superplasticiser

Table 8. Mix Set 3 of w/c 0.3’s average compressive strength results

| Batch | Design Mix [w/c 0.3] | SP [kg/m³] | Avg. Comp. Strength [N/mm²] for following no. of days |
|-------|----------------------|------------|-----------------------------------------------|
| 7     | 28 56 91             |            |                                               |
| Batch | Design Mix (w/c 0.5) | SP (kg/m³) | Avg. Comp. Strength (N/mm²) for following no. of days |
|-------|---------------------|-----------|-----------------------------------------------------|
| 1     | 100% OPC            | -         | 7 28 56 91                                           |
| 2     | 20% ePP             | -         | 49.15 58.05 59.35 61.33                              |
| 3     | 20% ePP+0.3% - SP1  | 2.1       | 33.37 47.22 50.69 53.64                              |
| 4     | 20% ePP+0.5% - SP1  | 3.5       | 57.48 71.22 72.25 82.48                              |
| 5     | 20% ePP+0.3% - SP2  | 2.1       | 58.33 72.02 72.08 77.37                              |
| 6     | 20% ePP+0.5% - SP2  | 3.5       | 60.53 72.21 73.53 75.24                              |
| 7     | 20% ePP+0.3% - SP3  | 2.1       | 56.08 66.77 77.19 77.54                              |
| 8     | 20% ePP+0.5% - SP3  | 3.5       | 54.17 68.41 70.29 72.14                              |

**Figure 5.** Mix Set 3 of w/c 0.3

**Table 9.** Mix Set 4 of w/c 0.5’s average compressive strength results
Mix Sets 1 and 2 as shown in Figures 3 and 4 show the compressive strength gain from 7 to 28 days. Mix Sets 3 and 4 of w/c 0.3 and 0.5 as shown in Figures 5 and 6 show compressive strength gain from 7 to 91 days. Based from observations, the compressive strength of design mixes incorporated with different percentages of superplasticisers for Figures 3 to 6 had slight increase and this shows that increase in percentages of superplasticisers does affect the cube’s strength gain. As for the 3 superplasticizers with ePP, according to Figures 5.2 to 5.5 the strength increased to 11-46% from 7 to 28 days of curing and still continually increased from 28 days until 91 days which presents a good sign of long term strength.

Figure 6. Mix Set 4 of w/c 0.5.
Meanwhile for 100% OPC according to Tables 7 to 9, there is an increase of 18% to 36% from 7 to 28 days curing and then consistently increase until day 91 at approximately 2-10%. As for 20% ePP and 80% OPC; it increases to 46% from 7 to 28 days curing for Mix Sets 1 and 2 (Figure 3 and 4) and 26-42% increase for Mix Sets 3 and 4 (Figures 5 and 6) and further consistent increase of approximately 3-7% until 91days. This shows that incorporation of ePP in the design mix gains strength as fast and sometimes faster and higher than 100% OPC mix and ePP is the reason why the other mixes with superplasticisers have higher increase in compressive strength as well. It is also shown that all cubes’ strength gain tends to be the highest at 7 to 28 days.

During fresh state, compaction on mixture of w/c 0.3 was challenging as the mixture hardens quicker compared to mixture of w/c 0.5. After casting; cubes of w/c 0.3 are evidently less smooth in appearance with visible voids externally due to the lack of water and even the superplasticisers could only promote the workability a little as seen from the slump results in Table 4. Meanwhile, the cubes of w/c 0.5 are observed externally to be well compacted with much less voids. Regardless; the cubes of w/c 0.3 provided the expected high strength results since cement content is much higher which is the main contribution to the cube’s strength. Curing beyond 91 days can be done to observe further strength increase until they become constant to determine their maximum strength gained. This shows that with the right amount of water to cement ratio, superplasticiser is a good combination with ePP in terms of quality and performance.

From both Figures 5 and 6; it can be seen the ePP design mix incorporated with SP3 seems to provide the best results meeting similar end strength results as 100% OPC for both 0.3 and 0.5 w/c ratios despite a failed slump test for w/c 0.5. This is not unexpected as SP3 is the latest formulated superplasticiser to enhance its ability on workability and other properties as mentioned previously.

3. Conclusion
The incorporation of recycled pozzolan, Eco Process Pozzolan (ePP) as partial cement replacement of concrete with the aid of various superplasticisers is therefore proven to be possible and effective producing high consistency and strength results. EPP’s limitation with workability is solved by incorporating superplasticisers into the mixes and it has been observed to not produce any side reactions and the cubes’ quality are as good and strong as cubes of full OPC. Furthermore; all 3 types of superplasticisers helped to increase the ePP mix’s workability and strength to match with 100% OPC mix with SP3 being the most effective with minimal percentage requirement in the concrete mixture. In overall, all design mixes of w/c 0.3 and w/c 0.5 compressive strengths continually increased with increasing curing days of 7 to 91 days.

4. References
[1] Pacheco-Torgal, F., Shasavandi A and Jalali S 2013 Eco-Efficient Concrete Using Industrial Wastes: A Review (Materials Science Forum) pp 730-732 pp 581-586
[2] Loh S K , Cheng, S. F., May C and Ngan, M 2006 A Study of Residual Oils Recovered from Spent Bleaching Earth: Their Characteristics and Applications (American Journal of Applied Science) volume 3 number 10 pp 2063-2067
[3] Muthengia J , Wa-Thiong’o and Muthakia G 2005 Spent Bleaching Earth as a pozzolanic Material (Journal of Civil Engineering Research and Practise) volume 2 number 1
[4] Al-Zahrani A A and Daous M A 2000 Recycling of Spent Bleaching Clay and Oil Recovery (Process Safety and Environmental Protection) volume 78 pp 224-228
[5] Nazrin S 2016 Performance of Eco Process Pozzolan Foamed Concrete as Cement Replacement pp 1-3
[6] Jarjusey K 2019 Evaluation of Eco Processing Pozzolan as a Partial Cement Replacement in Brunei pp 1036-1040
[7] Noordin M 2019 Feasibility of New Cement Replacement Material (EPP) in Brunei pp 25-38
[8] Mishra S and R. Tamrakar 2013 *Experimental Studies on Properties of Concrete due to different ingredient based Super Plasticizers* (International Journal of Science, Engineering and Technology Research) volume 2 pp 1036-1040

[9] Kovler K and Roussel, N. 2011 *Properties of Fresh and Hardened Concrete* (Cement and Concrete Research) volume 41 pp 775-792

[10] Alsadey S 2015 *Effect of Superplasticizer on Fresh and Hardened Properties of Concrete* (Journal of Agricultural Science and Engineering) volume 1 number 2 pp 70-74

[11] Duraman, SB 2018 Properties of Neat and Blended Concrete Systems Exposed to Standard 20C and Elevated 38C Temperature Conditions IOP Conference Series: Materials Science and Engineering, Volume 431, 2018 IOP Conf. Ser. : Mater. Sci. Eng. 431 052002

[12] Zainasallehen, SFH and Duraman, SB 2018 *Properties of PFA Concrete at Different Curing and Exposure Conditions in Hot Weather Environment* IOP Conference Series: Materials Science and Engineering, Volume 431, 2018 IOP Conf. Ser. : Mater. Sci. Eng. 431 052007

**Acknowledgements**

The Author acknowledges Pg Dr Saiful Baharin bin Pg Duraman for the beneficial discussions and support. Also to Readymix (B) Concrete Sdn Bhd and Hock Hin Trading Company for providing part of the materials used in the study and support in laboratory-works.