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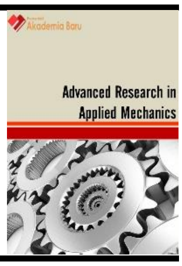

Compressive Strength of Eco-Processed Pozzolan Concrete under Chloride and Sulphate Exposure

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Elffie Yunus[1,*], Hidayati Asrah[1], Ahmad Nurfaidhi Rizalman[1]

[1] Faculty Engineering, Universiti Malaysia Sabah (UMS), Malaysia

ABSTRACT

Sulphate and chloride attacks on concrete are the notable issues in the field of durable concrete structures. Therefore, this study focused on the influence of Eco Process Pozzolan (EPP) ash on the strength performances of concrete exposed to sulphate and chloride environment. In this study the Ordinary Portland cement was partially replace with 10%, 20% and 30% of Eco process pozzolan ash by weight of cement and water to binder ratio of 0.45 was used in all concrete mixes. Eco process pozzolan is a solid waste generated from Spent bleaching earth after process of residual oil extraction was done. After demoulding samples were immersed in water for the curing period of 28 days. Afterwards, specimens were shifted in 3.5% Sodium chloride (NaCl) and 3.0% Sodium sulphate (Na2So4) solutions for additional curing periods of 7, 14 and 28 days. The short term effects of sulphate and chloride on the concrete were evaluated in terms of change in weight and variation in compressive strength. It was observed that the addition of EPP in concrete gives the lower loss of strength compared to the control mix when immersed in Sodium chloride and Sulphate chloride at the exposure period of 28 days. While, 10% of EPP has the lowest loss of strength compare to the other mix with EPP. This study suggests that 10% of EPP as supplementary cementitious material in concrete can reduce the negative effects of sulphate and chloride salts. The outcome of this study indicated that application of EPP as supplementary cementitious material in concrete increases the resistance against aggressive environment.

Keywords:
Eco process pozzolan, Sulphate attack, Chloride attack, compressive strength, Supplementary cementitious material

1. Introduction

Concrete is one of the materials which generally used in the construction industry. Concrete is produced by mixing water, cement, fine and coarse aggregates. It is widely used today to strengthen the structure for buildings and provide better durability.

However, concrete structures built with Ordinary Portland Cement (OPC) tend to deteriorate much faster under aggressive environmental conditions such as underground structure, marine structure and structure of wastewater treatment plants [16]. Therefore, the concrete performance of concrete structure could be affected due to its surrounding environment. In that case sulphate and chloride attacks are the paramount issues for the strength and durability of concrete structures [7]. Therefore, the Supplementary Cementitious Materials (SCM) were integrated in concrete construction for the enhancement of its strength and durability performances for sustainable concrete construction [22].

* *Corresponding author.*
E-mail address: Elffie Yunus (elffieyunus@gmail.com)

Currently, the common type of SCM used in concrete are Ground Granulated Blast-furnace Slag [34], Fly ash [2] and Silica Fume [25]. While, the current new SCM to partially replace OPC are Spent Bleaching Earth (SBE) [18] and Eco process Pozzolan (EPP) [20]. However, more study on these SCM are needed to improve the concrete properties through hydraulic or pozzolanic activity or both.

Spent Bleaching Earth (SBE) is discarded Palm Oil Refinery (POR) waste containing a high percentage of residual oil within in range of ~20-40% [4,15]. SBE has been incinerated for cement manufacturing but there is difficulty in maintaining good cement quality due to the high concentration of oil in SBE [23]. To ensure durability and stability of cement based structure; mixing and curing water should be free of crude oil spill as the compressive strength of materials will be affected if otherwise. However, Ting [26] reported that 30% of processed SBE performed better performance in strength and durability of foamed concrete exposed to chloride environment. Meanwhile, Chia [5] suggested, 60% SBE concrete show low result than 50% SBE, concluded that the percentage of SBE need to be reduce to ensure the concrete achieved its specific strength.

Eco-process pozzolan (EPP) is a solid waste material extracted from the waste product of crude palm oil degumming and bleaching process from refinery plants [24]. The waste product is called spent bleaching earth (SBE) generated from the edible oil processing. By replacing cement with EPP, waste problem can be reduced and economical concrete can be produced. Based on the laboratory test conducted, replacement of EPP that less than 30% show a better performance properties compared to control foamed concrete [20]. Despite having good performance properties, there is no study and data on durability of the EPP concrete. Hence, study on durability of the EPP concrete when exposed to chloride and sulphate is needed.

The main aim of this research is to determine the compressive strength of concrete containing Eco Processed Pozzolan (EPP) as supplementary cementing materials under chloride and sulphate exposure. Therefore, in this study 10, 20 and 30% of EPP were used to partially replace cement. In addition, to that concrete with and without EPP were immersed under 3.5% NaCl and Na_2SO_4 solutions for the short-term exposure period up-to 24 days was considered to evaluate the change of weight and compressive strength of concrete.

2. Material and Methodology

2.1 Materials

In this study Ordinary Portland cement (OPC) of Cap Gajah Brand was used, which meet requirements of Malaysian standard MS 522 and BS EN 197-1. The Eco process pozzolan (EPP) was collected from Eco Oils Sdn Bhd plant based in Lahad Datu, Sabah, Malaysia. It was visually observed that original EPP is mostly coarser and porous in nature as shown in Figure 1. The Scanning Electron Microscope (SEM) image of EPP as presented in Figure 2 shows that it has irregular, sharp, rough and porous structure.

The chemical and physical properties of EPP and OPC are provided in Tables 1. The chemical composition indicates that EPP contain mainly SiO_2 but has lower CaO compare to OPC. The sum of SAF is 69% indicates that the EPP can be classified as Class C pozzolan (ASTM C618). Class C pozzolan normally produced from lignite or subbituminous coal and having pozzolanic properties, also has some cementitious properties. The Loss on ignition of EPP is 2.7% higher than OPC, however still in a range of standard requirement as per ASTM C618.

Fig. 1. Eco Process Pozzolan Ash

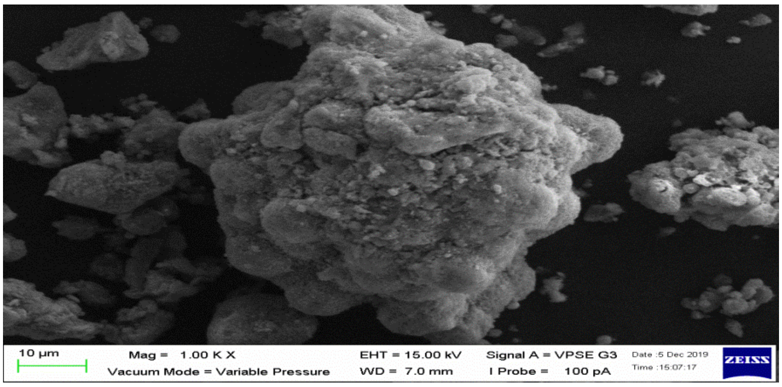

Fig. 2. SEM of Eco Process Pozzolan

Table 1
Chemical Composition of OPC and EPP

Oxides (%)	OPC [8]	EPP
SiO2	13.8	51.054
Al2O3	3.34	12.317
Fe2O3	3.83	5.862
CaO	56.89	13.321
MgO	1.88	5.701
SO3	3.51	3.654
LOI	0.441	2.7

2.2 Mix Proportions

Four types of concrete mixes were prepared. First mix with 100% Ordinary Portland cement (OPC), second mix with 90% OPC and 10% Eco Process Pozzolan (EPP), third mix with 80% OPC and 20% EPP and fourth mix 70% OPC and 30% EPP. The fine aggregate was passed through 4.7 mm sieve and coarse aggregate of nominal maximum size 20 mm was used. JKR method (Ministry of Works, 2005) method of concrete mix was adopted and material quantity was calculated as provided in Table 2.

Table 2
Concrete Mix Design (kg/m^3)

Description	Notation	Replacement (%)	Cement	EPP	Fine Aggregate	Coarse Aggregate	Water
Control mix (E0)	E0	-	430	-	516	1650	193.5
Concrete mix with 10% EPP	E10	10	387	43	516	1650	193.5
Concrete mix with 20% EPP	E20	20	344	86	516	1650	193.5
Concrete mix 30% EPP	E30	30	301	129	516	1650	193.5

2.3 Casting and Curing

Concrete cubes of size 100 mm were prepared with and without Eco Process Pozzolan (EPP) for the determination of compressive strength. Total 108 specimens were prepared, 27 of control mix, 27 of concrete containing 10% EPP, 27 of concrete containing 20% EPP and 27 of concrete containing 30% EPP as partial cement replacement. Concrete cubes were demoulded after 24 hours of casting and then all specimens were immersed in a water tank for the period of 28 days to get the designed targeted strength. Afterward 9 specimens of E0, E10, E20 and E30 each were shifted in each solution of 3.5% NaCl and 3% Na_2SO_4. Specimens were immersed under three different exposure conditions: under water, 3.5% NaCl and 3% Na_2SO_4 solution.

3. Results and Discussion

3.1 Workability

The workability of concrete was evaluated with slump cone method in according with ASTM C143 [28]. The workability of concrete mix E0 (control mix), E10, E20 and E30 are provided in Table 4. It can be seen that EPP concrete exhibit lower value of slump compared to slump of control mix concrete. It was also observed that among EPP results, the higher the EPP the lower the slump.

When EPP sample was scanned by electron microscope, the picture showed the EPPs, irregular, sharp, rough and porous surface, thus explaining its high specific surface area [9,32]. EPP concrete with high surface area required high quantity of water compare to the control concrete [6,27]. Hence, higher replacement of cement would cause the slump value to reduce.

Table 4
Workability of Concrete

Concrete Mix	Slump Value (mm)	Remarks
Control Mix (E0)	52	-
Mix with 10% EPP (E10)	36	30% reduction
Mix with 10% EPP (E20)	23	55% reduction
Mix with 10% EPP (E30)	17	67% reduction

3.2 Compressive Strength

Compressive strength results of concrete with and without EPP are presented in Table 4 and Figure 5. Under the water curing, the results demonstrated that concrete with 10% EPP was higher than 20% and 30% of EPP at early age. The reason is that the high of Portland cement type 1 (90%) in EPP concrete which induces higher hydration reaction than those of EPP 20% and EPP 30% concretes. Meanwhile, at 28 days compressive strength of E20 was 34.2 MPa which is higher than E10 and E30 concretes which were 33.1 MPa and 26.72 MPa respectively. E10 concrete has lower compressive strength than E20 concrete because concrete derives its strength from the pozzolanic reaction between silica in pozzolana and the calcium hydroxide liberated during the hydration of OPC at later age. At low percentages of replacement, it is explained the quantity of silica is low; therefore only limited quantity of CSH can be formed, though a large quantity of calcium hydroxide is liberated due to the relatively large quantity of Portland cement. Therefore, the strength of concrete at both low and high percentage replacement is low [22]. Osama [21] reported that the strength and durability of concrete is affected by the presence of ($CaCOH_2$) which is water soluble. Supplementary cementitious material (SCM) binds available ($CaCOH_2$) and produces more of the stable gel C-S-H and that is responsible for the strength development.

Therefore, replacing cement with increasing amounts of SCM forms more of C-S-H until a replacement ratio where the supply of ($CaCOH_2$) becomes too small to be bound by the available SCM. In this study, this happens when 30% of the cement is replaced with SCM [21].

Meanwhile, Wankhede and Fulari [3] studied the effects of fly ash on the properties of concrete and concluded that with 10% an 20% replacement of cement with fly ash, the compressive strength was increased whereas for 30% replacement, the strength decrease.

The current study shows that control concrete has high strength compare to concrete with 30% EPP of cement replacement. Concrete with 30% EPP produces lower strength than control concrete could be attributed to the lesser amount of total C-S-H gel produced. Lower cement content causes lesser hydration process in the concrete resulting in generation of lower amount of calcium hydroxide to be used in pozzolanic reaction for formation of C-S-H gel [13]. While, according to Abdul and Basid, [1], they conclude that 30% replacement of cement is the optimum amount to achieve the higher strength.

Table 4
Compressive Strength Result (MPa)

Mix	7-days	14-days	28-days
E0	21.14	28.64	30.13
E10	25.65	30.40	32.10
E20	22.27	31.66	34.20
E30	20.29	22.56	26.72

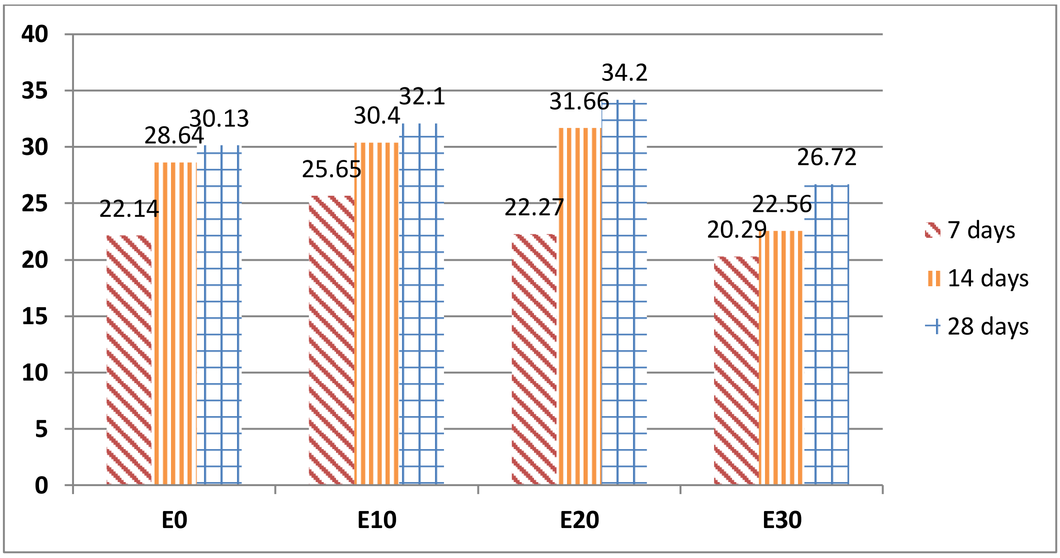

Fig. 5. Compressive strength Result

3.3 Compressive Strength of EPP Concrete under Chloride Exposure

The variation of compressive strength of concrete is provided in Table 5 and presented in Figure 6. In this study, the variation in compressive strength was obtained through the strength comparison of concrete E10, E20 and E30 with reference to E0 under different exposure conditions at the age of 7, 14 and 28 days. It was observed that E0 had the highest strength loss in the compressive strength at 28 days although E0 possessed the highest compressive strength at early age but it was only able to retained 73.24% of its seven-day compressive strength after 28 days. This indicates that E0 was affected the most in 3.5% sodium chloride environment. EPP added in concrete attributed to development of a finer pore structure as the SCM content increases, which reduces the rate of diffusion of aggressive solution into the concrete [11].

Meanwhile, concrete with E30 had the highest strength loss of 22.06 MPa compare to 27.89 MPa at seven-day. Mix E20 also showed a declining compressive strength trend that is 20.02%. However, it is not as severe as mix E0 (control mix). Mix E10 showed minimal changes in strength loss with less than 20% strength loss.

The reason which caused loss of strength may be chlorides are known to promote the leaching of calcium hydroxide Ca $(OH)_2$ and promote the formation of porous CSH involving complex reactions [14]. Hence, the leaching of calcium hydroxide and the formation of porous CSH attributed to concrete deterioration.

Table 5
Compressive Strength Results for 3.5% Sodium Chloride Exposure (MPa)

Mix	7-days	14-days	28-days	Loss (%)
E0	28.85	26.49	21.13	26.76
E10	28.81	27.79	23.74	17.79
E20	28.47	23.56	22.77	20.02
E30	27.89	26.21	22.06	20.90

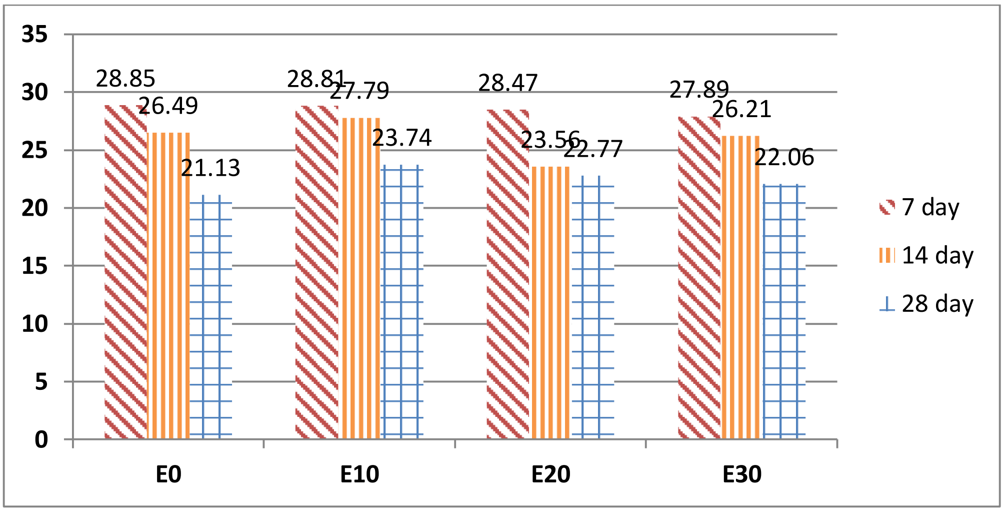

Fig. 6. Compressive strength of sodium chloride immersion

3.4 Compressive Strength of EPP Concrete under Sulphate Exposure

From Table 6 and Figure 7, it can be seen that the compressive strength has the similar trend as concrete mixes exposed to chloride environment. Mix E0 has the highest loss in the compressive strength compared to the other mixes that is 22.42%. The mix E30, E20 and E10 compressive strength respectively show decrease of 8.27%, 6.38% and 4.87% compared to the compressive strength of the control concrete. The strength loss may due to the chemical reaction between sulphate solutions and cement hydration products yet ettringite and gypsum to be found at later age. Ettringite are reported to cause expansion resulting to the failure of concrete specimens [10,17].

Table 6
Compressive Strength Results for 3% Sodium Sulphate Exposure (MPa)

Mix	7-days	14-days	28-days	Loss (%)
E0	28.63	26.09	22.21	22.42
E10	28.57	27.93	27.18	4.87
E20	28.35	27.88	26.54	6.38
E30	28.04	27.79	25.72	8.27

3.5 Change in Weight

The weight of concrete specimens was taken before and after exposure condition under sodium chloride and sodium sulphate. The results of change in weight of control mix (E0), concrete containing 10% EPP (E10), E20 and E30 at the curing of 7,14 and 28 days are provided in Figure 8 and Figure 9. It was observed that all sample of concrete did not show any weight reduction until 28 days.

From figure 8, it was observed that concrete E0 has the highest weight gained when compare to concrete containing EPP. This indicated that in the presence of EPP in concrete could reduce permeability [29, 30] and aggressive salts solutions which may cause deterioration on concrete.

While, concrete E10 has the lowest weight gained when compare to the concrete E20 and E30 which are 0.51%, 0.64% and 0.63 respectively.

The weight gains during immersion period up to 28 days under sulphate exposure could be attributed to a number of factors of sulphate solution, which include continued hydration of cement, formation of gypsum and increase in absorbed water in samples. Weight gained due to sulphate solution was also reported by Thokchom *et al.*, [31]. While, weight gain was observed for almost all specimens immersed in chemical solution due to solution absorption and expansion occurred by gypsum formation. This indicated that in the presence of EPP in concrete E10, E20 and E30 could reduce the permeability.

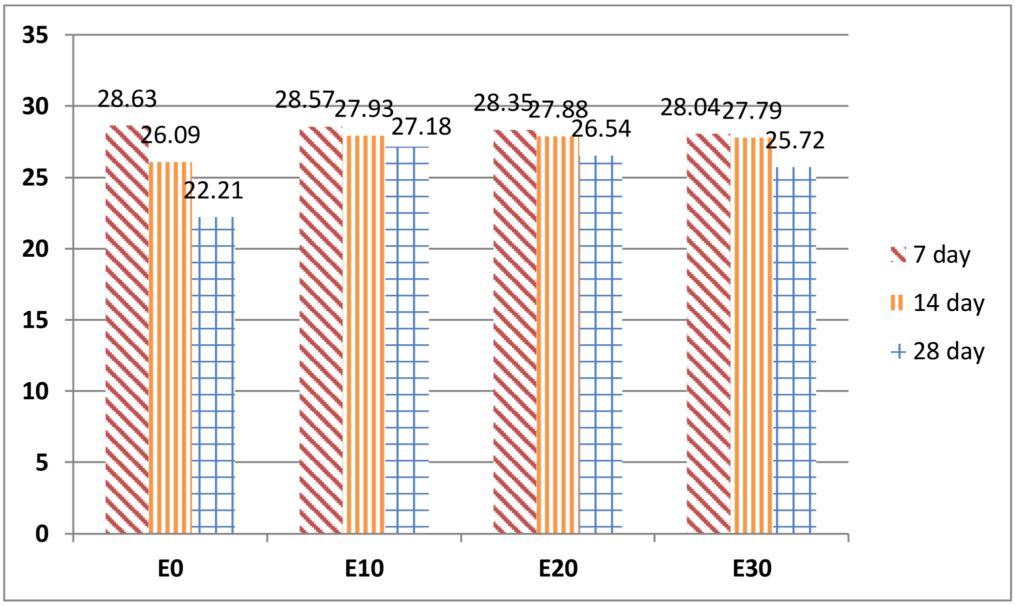

Fig. 7. Compressive strength of sodium sulphate immersion

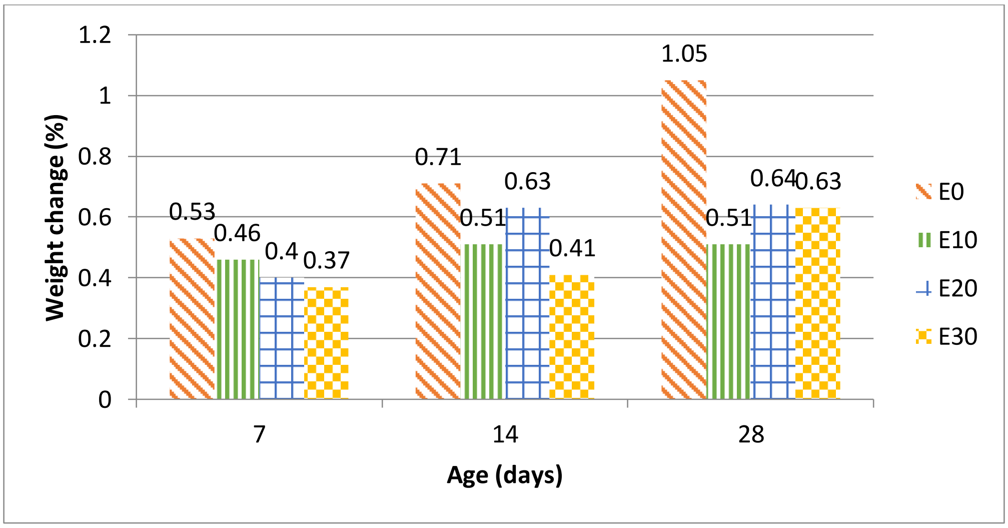

Fig. 8. Change in Weight of Concrete under Chloride Exposure

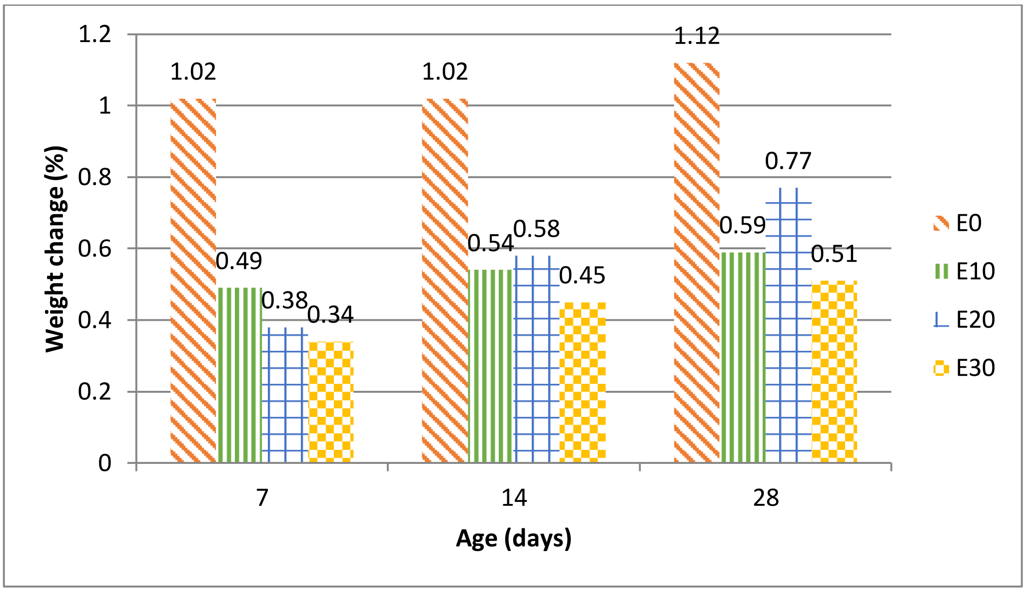

Fig. 9. Change in Weight of Concrete under Sulphate Exposure

4. Conclusions

Following conclusion could be drawn from the experiment study:

i. It was observed that concrete with and without EPP when exposed to 3.5% NaCl and 3% Na_2SO_4 solution, notable change in weight gain was observed in all mixes. The highest weight gain was observed in control mix (E0). However, the presences of EPP in concrete (E10, E20 and E30) could reduce the hydration process and decreases the salts penetrability, therefore less weight gain was observed in E10, E20 and E30.

ii. The strength performance of concrete with EPP is higher than the concrete E0 (concrete without EPP) cured in water at age of 28 days. It indicates that pozzolanic reactions between silica in pozzolana and the calcium hydroxide liberated during the hydration of OPC.

iii. The performance of concrete containing EPP (E10, E20 and E30) under 3.5% sodium chloride exposures was found to decrease the compressive strength and increase the weight of the concrete.

iv. Under 3% sodium sulphate (Na_2SO_4), concrete mix E10 has the highest compressive strength and concrete mix E0 has the lowest compressive strength. The highest weight gain was observed in control mix (E0).

v. The possibility of replacing ordinary cement with industrial waste such as EPP offers technical and environmental benefits which are importance in the current situation of sustainable development.

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