IOP Conference Series: Materials
Science and Engineering

PAPER • **OPEN ACCESS**

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IOP Conf. Series: Materials Science and Engineering **615** (2019) 012111 doi:10.1088/1757-899X/615/1/012111

Effectiveness of using pozzolanic material for concrete canal blocks in tropical peatland

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Abstract. The canal blocking system is commonly applied in to control water table in peatland recovery during prolonged dry weather in tropical peatland. The canal blocking is an effective strategy in preventing peat fire in many areas in Riau Province. Various local material such as earth, timber, sand, stone, rock, and concrete have been used in canal blocks. The concrete canal blocks are usually built at the river downstream and need to be stronger, durable and stable than other materials. Tropical peatland is a highly organic and highly acidic environment that could damage and reduce concrete structures service life in the long term. In this research, strength properties and porosity were evaluated to indicate the effectiveness of using pozzolanic material to increase resistance to the acid attack in concrete canal blocks. The concrete was produced by incorporating 10% Palm Oil Fuel Ash (OPC POFA) as a pozzolanic material from biomass to replace the Ordinary Portland Cement (OPC) cement content. The locally available commercial Portland Composite Cement (PCC) that contains pozzolanic material was also studied. The OPC concrete was used as a control mix with a target strength of 35 MPa. Specimens were cast and cured for 28 days in a laboratory water pond before subsequently placed in peat water canal nearby Rimbo Panjang Regency in Riau Province. The reduction rate in compressive strength, tensile strength, Young's Modulus of Elasticity, and porosity of concrete at 28, 91, 120 and 150 days were determined. Results show that the inclusion of pozzolanic material in concrete has increased the compressive strength, tensile strength, Young's Modulus of Elasticity and reduced the porosity. PCC and OPC POFA had better performance than the OPC concrete after immersed in the canal up to 150 days. Hence, it can be concluded that the pozzolanic material is effective in improving properties and acid resistance of concrete canal blocks in tropical peatland.

1. Introduction
As a strategy to restore peatland and to prevent peat fire, the Indonesian government has launched a regulation to build canal blocks in the area that is prone to nature and human-made disaster [1]. The canal blocking system is known very useful to raise the water table, to reduce runoff through the canals, to reduce flow velocity in the canals and to avoid erosion in the peatland [2, 3]. The canal block is enabling good water management and allowing peat restoration takes place to minimize carbon losses due to fire and oxidation and induce regrowth of vegetation in the peat ecosystem. Peat Restoration Agency (BRG) has given many pieces of training to the community in various locations in

Indonesia on how to build effective canal blocks [4]. Despite its effectiveness in controlling peat fire, there are some problems in canal blocks application such as high cost of construction, unavailability of materials, lack of quality of materials, non-standardized canal block design, and lack of a map of canal block location [5]. Furthermore, Giessen [6] highlighted the effectiveness of current canal blocks design such as dam type, dam condition, maintenance, capital cost and hydrological condition.

Canal blocks are usually built from locally available materials such as soil, sand, timber, rock, and concrete. From this study [6], the canal blocks need to be built on more solid footing to reduce premature deterioration due to fast subsidence of compressible peat soil. The quality of canal blocks depends on the material used in construction. Canal blocks from soil and sand only last for less than one year, while timber and rock blocks could be used for two years. Based on the Guidelines for Design and Construction of Check Dams for Prevention and Control of Peatland Fire [7], the concrete block has various type of construction such as precast stacked blocks, precast post-panel system and cast-in-situ concrete with a service life of more than five years. Concrete canal blocks are usually built in the river downstream that is adjacent to the coastal area. Figure 1 shows a typical concrete canal block used in peatland.

Figure 1. Typical concrete canal block in peatland (Courtesy of Sutikno, 2019).

Concrete is known to be vulnerable in acidic environments, both natural or synthetic acid environments. The type of acid, exposure time, acid concentration and degree of association of the acid determine the rate of concrete degradation. Generally, the acid dissolves calcium from the concrete that leads to an increase of porosity, a decrease of strength, and concrete hydration product damage [8]. Organic acid from natural water or land, such as peatland, could still be damaging to the concrete at a slower rate than a strong acid. This gradual attack is more noticeable after a long time of exposure, and the concrete degradation depends mostly on the concentration and composition of the organic acid. Due to the complexity of peat and its interaction with cement and metal, there are still not many studies in this area, especially exposure to the real environment. Most studies were carried out in a laboratory that covered degradation mechanism, cement type, attack of different kind of organic acids, and properties of concrete after exposure to the various variety of organic acids [9-11].

Properties of concrete in an organic acid in the peatland area was an important subject in the past few years. Some studies reported strength and porosity reduction of concrete, and corrosion of steel reinforcement exposed to organic acid in the first few weeks [12-16]. Inclusion of the pozzolanic materials such as fly ash, palm oil fuel ash (POFA), rice husk ash and silica fume in the concrete is advantageous to reduce the pores sizes and densify the microstructure of the concrete matrix. Furthermore, POFA is potential as a low-cost pozzolanic material for the concrete structure exposed to peatland, since Riau Province is one of the largest palm oil producers in Indonesia.

In this research, the effectiveness of a pozzolanic material, such as palm oil fuel ash was studied by placing the concrete in the peat canal up to 150 days. The efficacy of the pozzolanic material can also be emphasized by calculating the change in strength properties and porosity after exposure to water in the canal.

2. Materials and methods

Three types of the binder were used in this research, i.e. Ordinary Portland Cement (OPC), Portland Composite Cement (PCC) and OPC-Palm Oil Fuel Ash (OPC-POFA). A control mix was OPC concrete. PCC is a new type of commercial cement that contains less calcium than the OPC. The pozzolanic material used was POFA from a local industry incinerator in Pelalawan Regency. POFA was included as supplementary cementitious material by 10% of the cement weight for the OPC. The chemical composition of POFA is presented in table 1.

Table 1. Chemical compositions (wt%) of palm oil fuel ash and cements used in this study.

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	MnO_2	LOI	Others
POFA (%)	64.36	4.36	3.41	7.92	4.58	5.57	0.00	3.64	0.04	0.10	4.97	4.97
OPC* (%)	20.92	5.49	3.78	65.21	-	-	-	-	-	-	-	4.60
PCC* (%)	23.04	7.40	3.36	57.38	0.63	-	0.52	-	1.78	-	-	5.89

*[17, 18]

Peat water was taken from Rimbo Panjang Regency in Riau Province. The physical and chemical characteristics of peat water are shown in table 2. In general, the peat water composition was not within the permissible limits of drinking water. The water has a very low pH of 3.85 and high organic content of 328 mg/L.

Table 2. Physical and chemical composition of peat water.

Parameters	Unit	Results	Drinking water qualities [19]
Color	TCU	500	15
Turbidity	NTU	99.7	5
pH value	-	3.85	6.5-8.5
Organic content	mg/L	328	10
Alkalinity	mg/L	53	400
Iron (Fe)	mg/L	0.8	0.3
Manganese (Mn)	mg/L	0.1	<0.0248
Sulfate (SO_4^{2-})	mg/L	34	400
Chloride (Cl)	mg/L	31	250

Table 3 shows the mixture composition for the OPC, PCC and OPC POFA concrete with a target strength of 35 MPa.

Table 3. Mixture proportions for the OPC, PCC, and OPC POFA.

Mixes	OPC	PCC	OPC POFA
Cement (kg/m^3)	507.895	507.895	457.105
Coarse aggregate (kg/m^3)	987.425	987.425	987.425
Fine aggregate (kg/m^3)	684.138	684.138	684.138
Water (kg/m^3)	194.780	194.780	194.780
Palm oil fuel ash- POFA (kg/m^3)	-	-	50.789

The samples were cast in a 100x200mm mould and cured in a water pond for 28 days. The specimens were then placed in acidic peat water canal, Rimbo Panjang Regency, Riau Province up to 150 days until a testing date. Compressive and tensile strength was determined at 28, 91, 120 and 150 days in compliance with SNI 03-1973-1990 and SNI 03-2491-2002. Porosity values were measured at 28, 91 and 150 days after immersed in the water canal. The water canal has 5m width and approximately 1.0-1.50m depth. The pH of the water canal at the age of concrete testing were 3.6 between 3.89 at the time of testing. The pH values depend on the weather and seasons in Rimbo Panjang Regency, since the concrete exposure was carried out during transition between dry and rainy seasons.

The reduction rate of strength properties and porosity can be calculated using a similar expression for the following compressive strength equation:

$$R_C = \frac{R_{C0} - R_{Ce}}{R_{C0}} \times 100\% \tag{1}$$

R_C = reduction rate of change of compressive strength of cement concrete specimen
R_{C0} = compressive strength value after cured in a standard curing room for 28 days (initial strength value)
R_{Ce} = compressive strength value after exposure to peat canal water

By comparing the strength and porosity values with the initial strengths, the reduction rate could be calculated. Positive values mean the properties after exposure were lower than the initial properties, and vice versa. The reduction rate of change in compressive strength (RC), change in tensile strength (RT), change in Young's Modulus of Elasticity (RY), and change in porosity (RP) were plot as a function of time and type of cement. The correlation between those mechanical properties was also presented.

3. Results and discussion

3.1. Compressive strength

Reduction rate of compressive strength of the OPC, PCC and OPC-POFA exposed in the peat water canal after 28, 91, 120 and 150 days is presented in figure 2.

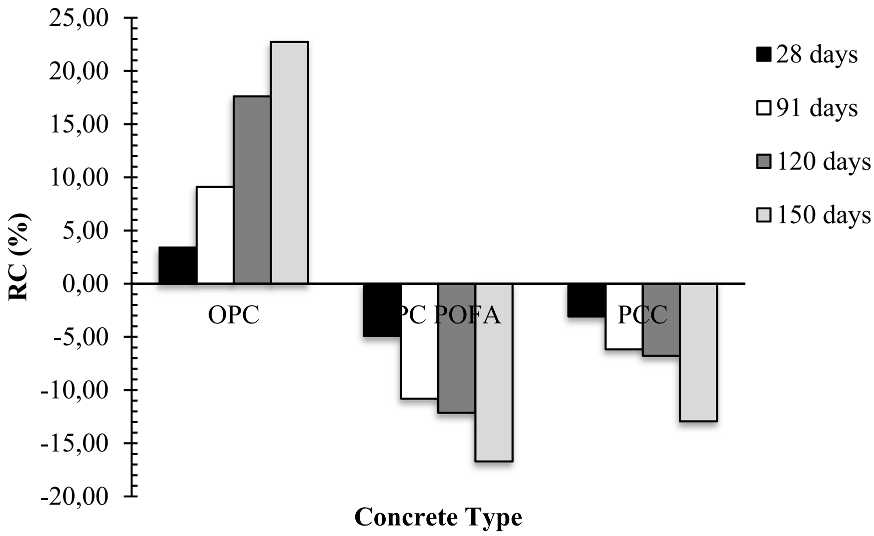

Figure 2. Reduction rate of compressive strength of the OPC, OPC-POFA and PCC concrete.

After exposure, the OPC concrete reduction rate gradually increased from 9.10%, 17.62% and 22.73% at 91, 120, and 150 days, respectively. The high reduction rate development is indicating a high decline in compressive strength of the OPC than other mixes. Both the OPC-POFA and PCC concrete performed lower reduction rate than the OPC. When comparing the reduction rate of the concrete produced with OPC-POFA and PCC, it was observed that the OPC-POFA had a lower rate of compressive strength reduction of 16.72% at 150 days, whereas the PCC concrete possessed 12.94%. At early ages, however, considerable strength reduction of 3.08% was observed in PCC concrete or the natural pozzolana blended cement. The test results revealed that the compressive strength reduction of concrete produced using pozzolanic material was lower compared to those with pure CaO cement. The reason behind this finding was that the pozzolanic material rich in SiO2 that react with $Ca(OH)_2$ to form Calcium Silicate Hydrate (CSH) physically improves the pore structure of the cement matrix. High CaO content made the OPC more susceptible to acid attack. Acid ions attack the hydration product of OPC, decompose the hydration product, and increase the porosity followed by the reduction of mechanical properties of the concrete [20]. On the other hand, the addition of pozzolanic material significantly increases concrete resistance to acid attack from peatland environment.

3.2. Tensile strength

Figure 3 displays the reduction rate of the tensile strength of OPC, OPC-POFA and PCC at 28, 91, 120 and 150 days. The rate of tensile strength loss of the OPC concrete was gradually increased from 41.18%, 45.16%, and 22.53% at 91, 120 and 150 days, respectively. The tensile strength reduction caused by a bonding destruction a the interface of the OPC matrix and aggregates in the control mix. Although peat water has weak organic acid, however, it still gives a considerable attack into the concrete using pure and high calcium content cement. Continuous exposure to the peat water of canal block made from OPC concrete certainly is not recommended, since it deteriorates the strength even after 28 days exposure to the peatland.

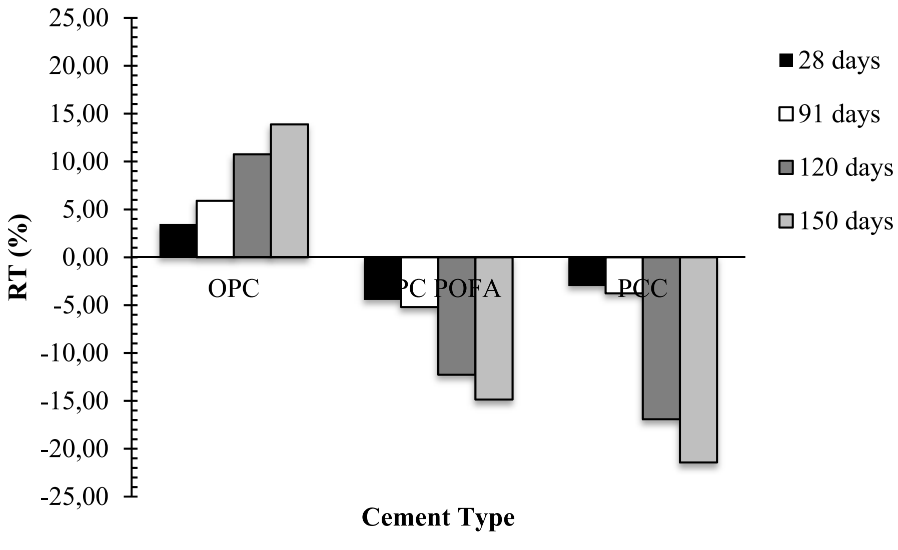

Figure 3. Reduction rate of tensile strength of the OPC, OPC-POFA and PCC concrete.

In reverse, mix PCC and the OPC-POFA had gradually increased in the tensile strength than the OPC concrete after exposed to peat water up to 150 days. It was observed that the tensile strength followed the same trend as the compressive strength because there is a direct relationship between the pore densification and increased strength after exposure in peat water. Both OPC-POFA and PCC gained as considerable strength from 28 days to 150 days by 70% and 85.95%, respectively. Inclusion of pozzolanic material in the concrete mix produces a pozzolanic reaction and pozzolanic product

(Calcium Silicate Hydrate gels) that improve the weak region of Interfacial Transition Zone (ITZ) of the concrete microstructure. The ITZ or the zone between aggregate surface and cement matrix is responsible for improving the microstructure, thus the elastic properties of concrete. The results were in line with a previous study about the effect of using pozzolanic materials such as slag to enhance the bond between the aggregates and cement matrix trough microstructure improvement [21]. From this research, it is obviously recommended to opt for pozzolanic material or using pozzolan based cement to build canal block that is continuously exposed to peat water for a very long time.

3.3. *Young's modulus of elasticity*

Young's Modulus of Elasticity (YM) represents a stiffness of material under certain exposures. Figure 4 shows the elastic modulus of OPC concrete decreased by 52.33% after exposed to peat water at 150 days. A gradual reduction of the Young's Modulus of Elasticity of the OPC concrete was observed. This behaviour aligns with the tensile strength since the OPC contains calcium hydroxide that reacts with the acid in peat water; thus, it has an adverse impact on the modulus of elasticity. A change in elastic modulus of OPC POFA and PCC concrete was considered significant, varied between 49.79-96.86% at 150 days. This proves that the peat water has a minor effect on modulus elasticity of OPC POFA and PCC. An increase of stiffness or modulus of elasticity of both type of concrete despite a long immersion in peat water. The PCC concrete performed a significant change in stiffness than the OPC concrete due to pozzolanic material in the concrete. This behaviour is favourable for canal block in the river downstream.

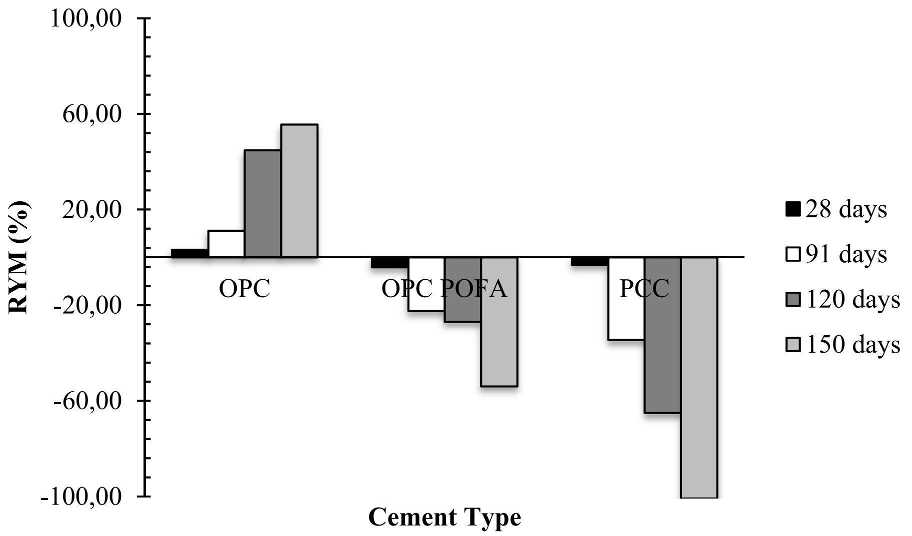

Figure 4. Reduction rate of Young's Modulus of the OPC, OPC-POFA and PCC concrete.

3.4. *Porosity*

The reduction rate of porosity for OPC, OPC POFA and PCC specimens at 28, 91 and 120 days are presented in figure 5. It can be observed that the porosity's reduction rate of OPC concrete increased at 28 days by 3.64% but continues to experience a decline up to 150 days by 16,54%. This clearly shows the acid attack influences the porosity of the plain cement (OPC). An increase in porosity of the OPC concrete under continuous immersion in water canal might be due to the microstructure alteration after the acid ion decomposed CaO and hydration product. It is also shown that there was an opposite trend for OPC POFA and PCC concrete with a considerable decrease of porosity after 91 days. The porosity of OPC POFA and PCC decreased by 24.39% and 15.81% at 120 days, with a reduced rate for each specimen was 18.14% and 17.85%, respectively. These values continue to increase up to 150 days with the highest reduction rate of porosity shown in OPC POFA by 22.71%. The improvement could be due to continuous hydration and the pozzolanic reaction of the specimens after being subjected in the peat water canal. This clearly shows that the pore development of concrete in peat water canal immersion is affected more by the cement composition, such as the inclusion of pozzolanic material in blended cement.

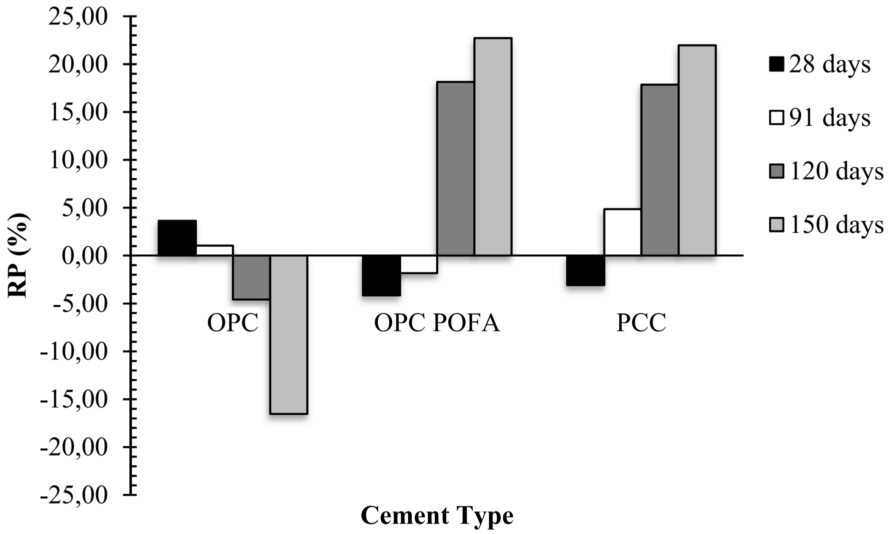

Figure 5. Reduction rate of porosity of the OPC, OPC-POFA and PCC concrete.

3.5. *Effectiveness of pozzolanic material in concrete canal blocks*

Canal blocks in peat water exposed to low bearing capacity and aggressive environment peatland. Concrete canal blocks in downstream are usually made from concrete due to the ease of operation, maintenance site accessibility, and service life of the structures. Most of the blocks in the downstream has a dual function as a culvert, road culvert, and bridge crossing. Despite a high capital cost for manufacturing concrete, a permanent concrete canal block such as stacked blocks and the post-panel system has better life service of more than five years. Compared to the low-cost canal blocks from earth, timber or stones, the concrete canal blocks have better water retention and low maintenance cost. Based on the guideline [7], the concrete canal blocks need to be built permanently, and it needs to have the strength of more than 25 MPa with a concrete cover of 40mm and uses pozzolanic material to increase the acid resistance. Furthermore, the canal blocks must be useful structurally, such as excellent water retention, good mechanical strength and stability (solid footing) against the water stream and flooding.

The influence of pozzolanic material in concrete canal blocks to increase acid resistance based on enhancing strength properties such as compressive and elastic properties (tensile and modulus of elasticity), and improve the water tightness as shown in figure 6. Figures 6(a) and 6(b) displays the tensile strength and modulus of elasticity increases with an increase the compressive strength. This clearly shows that the strength grade has a significant influence on the elastic properties development of the concrete. OPC POFA and PCC still perform a gradual strength gain after immersed in peat water up to 150 days, which is beneficial for concrete canal blocks structural resistance and stability. Moreover, in figure 6(c), a reduction of porosity with an increase in compressive strength shows the mixture composition of cement influences the porosity in concrete. The pozzolanic material in OPC POFA and PCC effectively induced a further reaction that improved the size of the pores and types in the concrete through the formation of Calcium-Silicate-Hydrate (C-S-H). The continuous formation of the hydration product (C-S-H) has improved the strength, reduced the porosity, and increase the effectiveness of concrete after exposure to the peat canal water. Thus, the pozzolanic material is an effective material for concrete canal block exposed to an aggressive environment in the long term.

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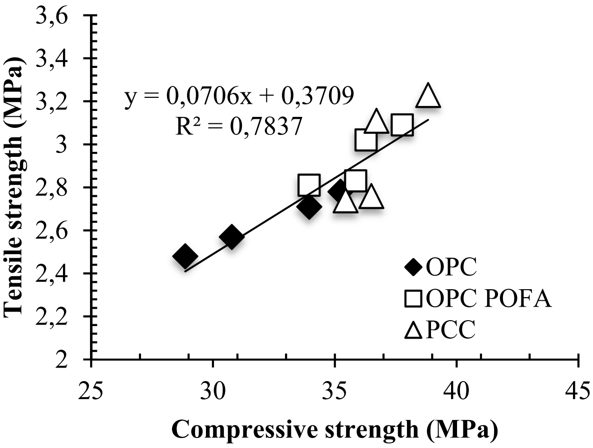
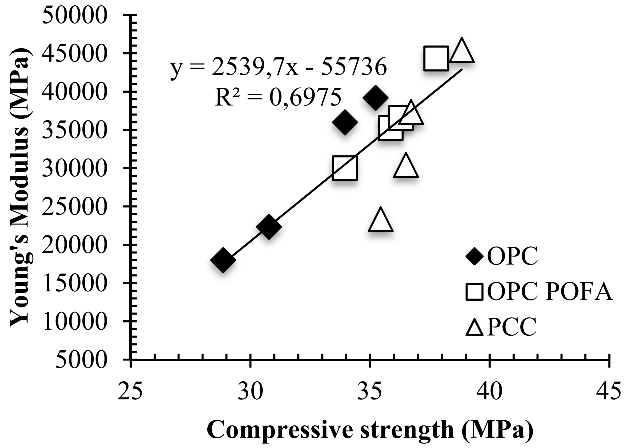
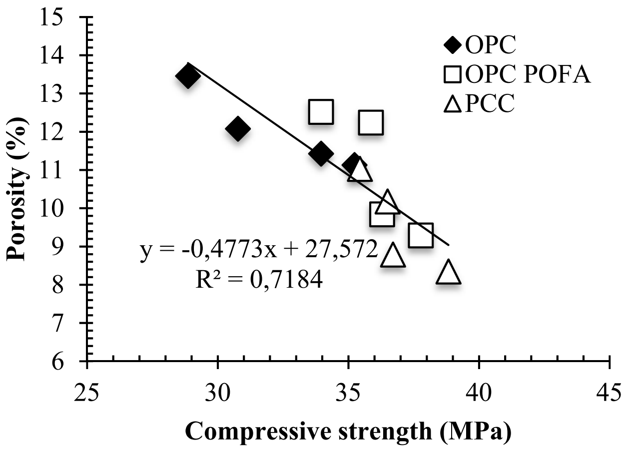


(a)



(b)



(c)

Figure 6. Variation of (a) tensile strength, (b) Young's Modulus of Elasticity, (c) porosity with compressive strength of OPC, PCC and OPC-POFA concrete.

4. Conclusions

This study aims to investigate the effectiveness of using pozzolanic material to improve mechanical properties and porosity of the OPC, PCC and OPC POFA concrete as canal blocks material in tropical peatland. The specimens were subjected to peat water up to 150 days in the peat canal. In general the OPC POFA and PCC concrete that contains pozzolanic material performed strength gain up to 150 days, while OPC concrete showed a significant strength reduction. The rate of decrease in compressive strength, tensile strength and Young's Modulus of concrete using pozzolanic material were less than the OPC concrete. There was a high reduction of porosity of the OPC POFA and PCC than the OPC concrete. This improvement was due to the influence of pozzolanic material that increased the strength of concrete and reduced its porosity through the formation of Calcium-Silicate-Hydrate (C-S-H). Thus, the pozzolanic material is an effective material for concrete that was directly exposed to an aggressive environment in the long term.

Acknowledgment
The authors would like to acknowledge funding from Penelitian Unggulan Perguruan Tinggi (PUPT) 2017, Lembaga Penelitian, Universitas Riau, Pekanbaru, Indonesia.

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