

PERFORMANCE OF WASTE TYRE AND PALM OIL FUEL ASH CONCRETE

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Abstract: The performance of concrete mix in the presence of tyre particle and Palm Oil Fuel Ash (POFA) was investigated and compared with control mix. Tyre particle was used as sand replacement whereas POFA was used as a cement replacement. The proportion of the tyre particle varied in a percentage of 10%, 20% and 30% sand replacement while the proportion of POFA was fixed at 20%. Control specimen mixed with 0% POFA. And 1% of superplasticizer was added into concrete mix to improve its workability. The concrete was cured in water and was tested at 7, 14, 28 and 56 days. The tests conducted were slump test for workability and mechanical properties test (compressive, tensile, and flexural strength). The results showed that tyre particles decrease workability and the mechanical properties of concrete. The compressive strength and indirect tensile strength of concrete contain 20% POFA increases while its flexural strength decreases.

Keywords: Waste tyre, palm oil fuel ash, rubberized concrete, mechanical strength

1.0 Introduction

In recent years, due to the rapid development of the automobile industries which result in high demand of cars as a means of transportation, it has tremendously boosted tyre productions. As a result of this increase in tyre production, millions of tyres have been discarded into open fields in form of scrap or waste. There is need for the proper recycling and utilization of such waste, which if not properly disposed, recycled and reused, can cause an environmental pollution. These stockpiles are dangerous not only due to potential environmental threat, but also providing a breeding ground for mosquitoes since tyres often hold water inside which remained warm enough for optimal mosquito breeding. Mosquitoes create a nuisance and may increase the likelihood of spreading disease. Waste tyre creates a fire danger, since a large tyre pile is

flammable. Some tyre fires have burned for months, since water does not adequately penetrate or cool the burning tyre. Tyres have been known to liquefy, releasing hydrocarbons and other contaminants to the ground and even ground water, under extreme heat and temperatures from a fire. The black smoke from a tyre fire cause air pollution and is a hazard to downwind properties. (Guneyisi *et al.*, 2004; Siddiquel and Naik, 2004; Khatib and Bayomy, 1999; Li *et al.*, 2004)

Palm oil industry is one of the most important agro-based industries in Malaysia. Besides the production of crude palm oil, a large amount of solid waste is also an output from the palm oil industry. Annually, more than two million tons of solid waste of palm oil residue, such as palm fibre, shells and empty fruit bunches are produced (Ahmad *et al.*, 2008). Utilization of POFA is minimal and unmanageable, while its quantity increases annually and most of the POFA are disposed of as waste in landfills causing environmental problems. On the other hand, many researchers have studied the use of agro waste ashes as constituents in concrete, namely rice-husk ash (Mehta, 1977), sawdust ash (Udoeyo & Dashibil, 2002) and bagasse ash (Singh *et al.*, 2000). The results revealed that these agro waste ashes contained a high amount of silica in amorphous form and could be used as a pozzolanic material. According to ASTM C 618 (2001) defines pozzolanic material as a material that contains siliceous or siliceous and aluminous material by composition. Pozzolanic materials such as POFA can be used as a partial replacement material of cement in concrete to reduce the cost of concrete production and to modify some of the concrete properties in fresh and hardened state (Awal and Abubakar, 2011).

Over the years, the cost of concrete which is the most important and most commonly used construction material keep on increasing. The main reason for the increment in concrete cost is due to shortage of its constituent material which therefore increases the cost of the constituent materials. Concrete constitute materials such as cement, fine aggregate, coarse aggregate, water mixed in a designed proportion to produce a solid paste of desired strength and durability properties. Cement is the most expensive concrete material, while aggregate constitute the bulk volume of concrete. In order to reduce the cost of concrete and the shortage of its constituent materials, there is a need to develop other materials which can substitute concrete constituent materials. These new materials are mostly waste products and by-products which if used in concrete will reduce both environmental pollution and the cost of concrete and at the same time modifies one or more properties of the concrete. The continuous research and development of concrete has resulted in the production of many types of concrete. Each of the concrete possesses their own unique characteristic to meet and suit the demand of industry. Although there are many advantages of concrete such as high compressive strength and low maintenance, the disadvantage is its low loading toughness compared to other materials. Therefore, an alternative material such as waste tyre particles is used as a replacement for concrete aggregate to possibly remedy or reduce such negative

attribute. Elastic and deformable tyre-rubber particle could improve concrete properties. (Khaloo *et al.*, 2008; Li *et al.*, 2004).

Khaloo *et al.*, (2008) studied the properties of concrete containing high-volume rubber particles. They observed that the workability of concrete is affected by the interaction of tyre particles and mineral aggregates. They observed that the slump of concrete increases with tyre aggregate concentration lower than 15% and reaches its maximum when the tyre concentration was 15%, the tyre aggregate concentration exceeding 15% reduced the slump. Tang *et al.*, (2012) reported that the workability of concrete containing chipped tyres was generally lower than that of the control concrete showing a range of 35 – 55mm slump, the slump value was found to decrease as the size and proportion of chipped tyres increased. They also reported that increased chipped content would increase the consumption of mixing water and cement paste for coating the surface area of the shreds, which thus decreased the workability.

Khaloo *et al.*, (2008) reported that the substitution of mineral aggregates with tyre–rubber particles in concrete results in large reductions in ultimate strength and the tangential modulus of elasticity. Due to the considerable decrease in ultimate strength, rubber concentrations exceeding 25% are not recommended. Pre-treatment of tyre particle surfaces should be considered for possible improvement of tyre–rubber concrete mechanical properties. Sukontasukkul and Tiamlom, (2012) reported that the results on the compressive strength and elastic modulus both appear to decrease when crumb rubber is incorporated into the mix. They also stated that as for the effect of crumb rubber size, both compressive strength and elastic modulus are significantly affected by the size of crumb rubber. The decrease of both properties is more pronounced when the smaller crumb rubber is used. Li *et al.*, (2004) reported that the strength and stiffness of waste tyre rubber modified concrete are lower than those of the control concrete, regardless of chips or fibres. This is understandable because tyre rubbers are much softer than the concrete matrix.

Ganjian *et al.*, (2009) produced two mixes and studied the effect of tyre rubber in the mixes. In the first mix they replaced coarse aggregate particles with chipped tyre rubber, and in the second mix they replaced cement with ground tyre rubber. They reported that the tensile strength of concrete was reduced with replacement of rubber in both mixtures. The percentage reduction of tensile strength in the first mixture was about twice that of the second mixture for lower percentage of replacements. Ganjian *et al.*, (2009) also observed that replacement of rubber reduces flexural strength as expected. They studied two mixes, in the first mix coarse aggregate was replaced with chipped tyre rubber and in the second mix cement was replaced with ground tyre rubber. The reduction in flexural strength occurred in both mixtures and only the rate was different. A reduction of 37% with respect to the control sample was observed in the first mixture. This value reached to 29% for the second mixture. Hence, research on the use of rubber in concrete is not conclusive until today.

Abu (1990) the pioneer in POFA research has embarked on studying agricultural ash in Malaysia and finally acknowledged that POFA is a pozzolanic material and able to be replace as partial cement replacement up to 35% in mortar mix that could exhibit similar strength as control mortar. Then, studies have been continued by Awal and Hussin (1996) that highlighted that POFA concrete gain maximum strength when 30% of the cement was replaced with POFA but further increase in the ash content would reduce the strength of concrete gradually. Increasing in fineness of POFA would lead to greater concrete strength development than the coarser one (Awal and Hussin, 1996).

In this study, the mechanical properties and curing period comparison between each mix were studied. The performance of concrete mix in the presence of rubber aggregate and POFA was investigated and compared with normal mix. The optimum amount of rubber aggregate to use in concrete was investigated, and the properties of concrete containing rubber aggregate and POFA both in fresh and hardened state were also investigated. The properties includes; workability and mechanical properties (compressive strength, indirect tensile strength, and flexural strength test).

2.0 Materials and Methods

2.1 Rubber Aggregate

Tyre particles from scrap tyres were provided from Yong Fong Rubber Industries Sdn Bhd Malaysia In this study, the crumb was used as aggregate in concrete. The maximum size of rubber aggregate used was 3.36 mm; this was obtained by conducting sieve analysis of the rubber particles to get particle sizes ranging between 0.84 mm to 3.36 mm. Fig 1 shows the crumb rubber particle prepared and used for the research work. The chemical properties of rubber used were shown in Table 1, and its physical properties shown in Table 2.



Figure 1: Crumb Rubber

Table 1: Chemical properties of rubber particles

Chemical Composition	Values (%)
Acetone Extract (ISO 1407)	10±3
Ash Content (ISO 247)	24±3
Carbon Black (ISO 1408)	14±8
Rubber Hydrocarbon (RHC) by difference	52±5

Source: (Yong Fong Rubber Industries Sdn. Bhd.Malaysia)

Table 2: Physical properties of Rubber

Physical Properties	Unit	Values
Size (ASTM D5644)	mm	1-4 and 5-8
Heat Loss (ASTM D1509)	kgf/cm ²	<1%
Metal Content (ASTM D5603)	%	<0.5%
Fiber Content (ASTM D5603)	ML (Vr)	<1%

Source: (Yong Fong Rubber Industries Sdn. Bhd.Malaysia)

2.1 Palm Oil Fuel Ash

Palm oil fuel ash (POFA) used in this research was obtained from a palm oil mill located in Kluang, Johor Malaysia. Firstly the POFA was oven dried at a temperature of about 110oc for two days and later sieved through a 212µm sieve in order to remove bigger-sized ash particles and impurities. Finally, the POFA was put in a grinder to get finer POFA size. The chemical composition of POFA shows in Table 3.

Table 3: Chemical composition of POFA

Chemical Composition	CO ₂	SiO ₂	Al ₂ O ₃	K ₂ O	Fe ₂ O ₃	CaO	P ₂ O ₅	MgO	SO ₃	Cl	TiO ₃
Values (%)	0.10	62.60	4.65	9.05	8.12	5.70	3.86	3.52	1.16	0.45	0.41

2.1 Preparation of Samples and Test Procedures

The concrete mix consists of cement; fine aggregate, coarse aggregate, water, POFA, and tyre particles. The concrete mix was designed based 30 MPa at 28 days, with water-cement ratio of 0.45 where 1% superplasticizer was added to improve workability. The mix design was done in accordance to ACI 318. Fine aggregate was replaced by 10%, 20% and 30% rubber material in different concrete mixes. For each batch 200 mm height and 100 mm diameter and small beam samples of 100x100x500 mm were produced. The samples were cured in water for 7, 14, 28 and 56 days according to ASTM/C192M. Table 4 shows the constituent materials of each concrete mix. The slump test is sensitive to changes in the consistence of concrete, which correspond to slumps between 80 mm and 100 mm. The test was conducted according to ASTM C143.

For the compressive strength test, the test in conducted in accordance with ASTM C 39. In the flexural strength, a total of nine beam samples with dimensions of 100mm X 100mm X 500mm were prepared for each percentage replacement of fine aggregate particles with tyre particles (10%, 20%, and 30%) in concrete,. The test was carried out for 7, 14 and 28 days. Two-point loading test was carried out to obtain the flexural strength of the beam. The testing procedure and manual were conducted based on ASTM C348-08, C293-10. The test of indirect tensile strength of concrete was followed based on ASTM C 496. Cylinder samples of 100 mm diameter and 200 mm height were prepared for each percentage partial replacement with tyre particle and POFA (0%, 10%, 20%, and 30%).

Table 4: Concrete mix design, Grade 30 MPa, Based on ACI 318

Mix	Cement (kg/m ³)	POFA (kg/m ³)	Super Plasticizer (kg/m ³)	Water (kg/m ³)	Fine Aggregate (kg/m ³)	Fibre Rubber (kg/m ³)	Coarse Aggregate (kg/m ³)
CP	449	-	4.49	202	837	-	907
CP20	359.2	89.8	4.49	202	837	-	907
R 10 CP20	359.2	89.8	4.49	202	753.3	26.87	907
R 20 CP20	359.2	89.8	4.49	202	669.6	53.75	907
R 30 CP20	359.2	89.8	4.49	202	585.9	80.62	907

In which,

CP : plain concrete/normal mix/control mix

CP20 : plain concrete with 20% POFA

R10CP20: plain concrete with 10% rubber aggregate and 20% POFA

R20CP20: plain concrete with 20% rubber aggregate and 20% POFA

R30CP20: plain concrete with 30% rubber aggregate and 20% POFA

3.0 Results and Discussion

3.1 Compressive Strength

The result of compressive strength test for control concrete (CP), concrete with 20% POFA (CP20) and rubberized concrete (10%, 20%, and 30%) were shown in Fig 2. The compressive strength was increased by increment of curing period. This is due to the increase in hydration of the concrete with curing, which in turn results in an increase in compressive strength of concrete.

As the percentage replacement of fine aggregate with crumb rubber in the concrete containing 20% POFA (CP20) increases the compressive strength of the concrete decreases as shown in Fig 2 and Table 5. When 10% of fine aggregate was replaced with crumb rubber, there was a sudden decrease in compressive strength by about 24%, and when replaced by 30% a further decrease of up to 39.3% was noticed. This decrease can be due to either of the following

- i) As cement paste containing rubber particles surrounding the aggregates is much softer than hardened cement paste without rubber, the cracks would rapidly develop around the rubber particles during loading, and expand quickly throughout the matrix, and eventually causing accelerated rupture in the concrete
- ii) Due to lack of proper bonding between rubber particles and cement paste compared to aggregate and cement paste, which causes non uniform distribution of applied stress. This results in cracking at the boundary between the cement paste and aggregate which in turn results to a decrease in compressive strength.
- iii) Since parts of the fine aggregates is replaced with rubber, which has a lower unit weight compared to the natural aggregates, this causes a reduction in the concrete unit weight and hence its volume. Compressive strength depends on the mechanical and physical properties of these materials, hence a reduction in compressive strength is expected.
- iv) As rubber is softer and less stiff than natural aggregates, replacing aggregate with rubber results to a concrete which has lower mass stiffness and hence lower load carrying capacity. Also since rubber is softer, concrete containing rubber particles easily

Table 5: Percentage gain/loss of compressive strength at 28 days

Mix	Compressive strength 28 days	% Strength gain at 28 days (design 30 MPa)	
control concrete	CP	33.218	-
20% POFA	CP20	34.44	$34.44 - 33.218 / 33.218 = 3.7$
10% rubber aggregate with 20% POFA	R10CP20	25.277	$33.218 - 25.277 / 33.218 = 23.9$
20% rubber aggregate with 20% POFA	R20CP20	20.150	$33.218 - 20.150 / 33.218 = 39.3$
30% rubber aggregate with 20% POFA	R30CP20	17.920	$33.218 - 17.920 / 33.218 = 46.1$

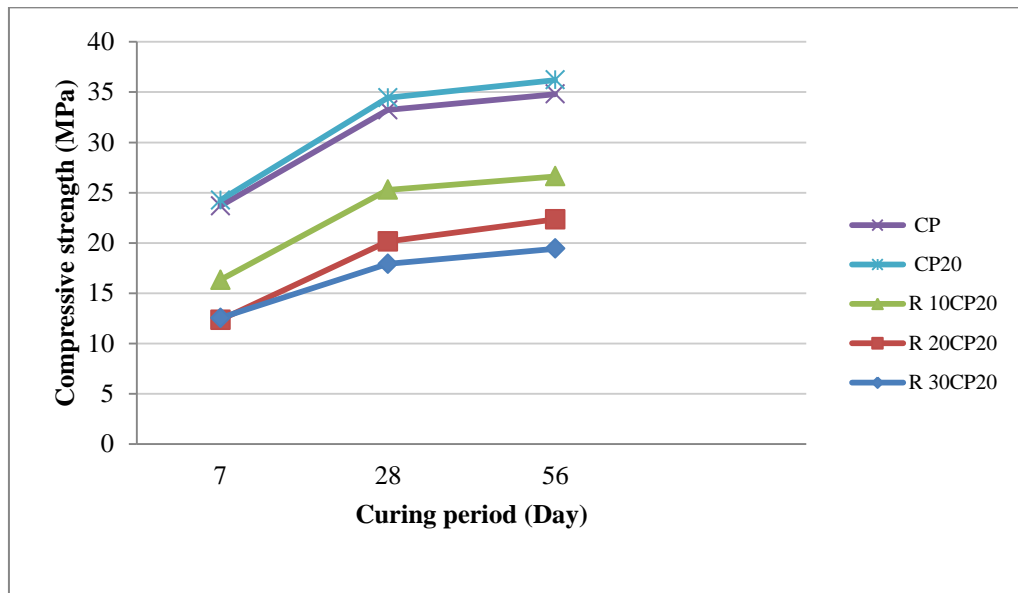


Figure 2: Variation of Compressive Strength with time

Issa and Salem, (2013) studied utilization of recycled crumb rubber as fine aggregate in concrete mix design and found that when 15%, 25%, 50% and 100% fine aggregates was replaced with crumb rubber in concrete, the compressive strength decreases by 17.9%, 36%, 59.2% and 83.7% respectively. This was less than compared to fine aggregates replaced with crumb rubber in CP20 as shown in Table 5. This is because of the presence of POFA which increases the compressive strength in concrete. Aiello and Leuzzi, (2010) carried out a similar research work, they found that when 50% and 75%

by volume of fine aggregate was replaced with crumb rubber a compressive strength decrease of about 28% and 37%, respectively was noticed compared to the control mixture.

3.2 Flexural Strength

The result of flexural strength test for control concrete with 0% rubber (CP), concrete with 20% POFA (CP20) and rubberized concrete (10%, 20%, and 30%) were shown in Fig 3. The flexural strength of rubberized concrete was increased by increment of curing period. The 28 days flexural strength of the control concrete (CP) was higher than that of concrete containing 20% POFA (CP20). As fine aggregate was replaced by different proportion of rubber in CP20, the flexural strength was less than that of both CP and CP20, but the flexural strength increases with increase in rubber proportion. This is because rubbers are good in terms of tension and provide post cracking ductility and toughness for the concrete. Li *et al.*, (2013) carried out a similar research; they found that the flexural strength of rubber concrete reduced quickly when the ratio of crumb rubber was between 0% and 20%. While the ratio of crumb rubber is between 40% and 60% the flexural strength of it reduced slowly. Again from Fig 3, the flexural strength of CP20 was similar to that of the control at 7 days curing. As the days of curing increases, the flexural strength of CP becomes lower than that of the control. Sooraj, (2013) carried out a similar report on POFA. He found that the flexural strength test results of palm oil fuel ash concrete for the 28 day flexural strength of 10% replacement of cement with POFA is similar to that of the control mix. When he increased the replacement proportion to 20%, the flexural strength also increases. But, as he further increases in proportion of POFA, it causes a reduction of Flexural Strength.

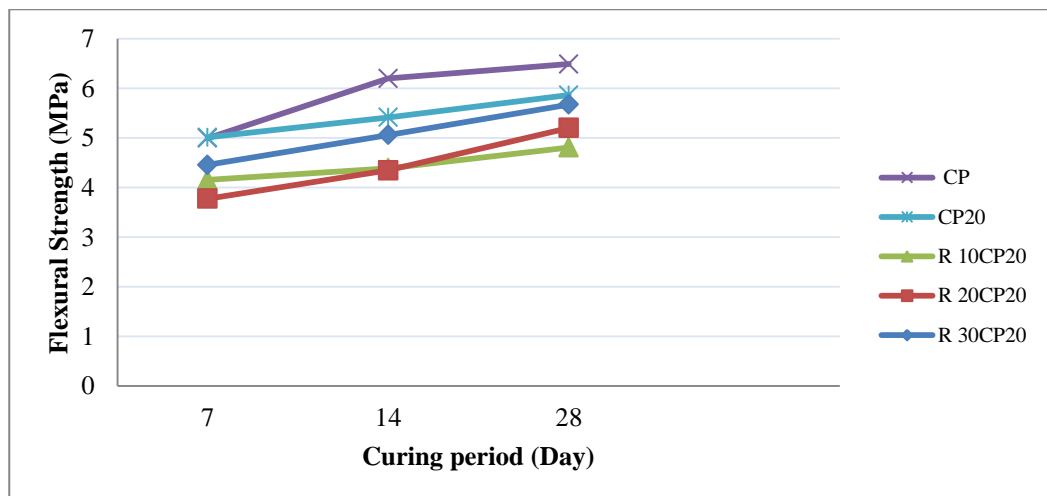


Figure 3: Variation of Flexural strength with time

3.3 Indirect Tensile Strength

The result of indirect tensile strength test for control concrete with 0% rubber (CP), concrete with 20% POFA (CP20) and rubberized concrete (10%, 20%, and 30%) were shown in Fig 4. The indirect tensile strength was increased by increment of curing period. However, the indirect tensile strength of rubberized concrete was decreased by increment of percentage rubber aggregate but the strength of R30CP20 was found to be higher than for R20CP20 at 7 and 28 days. At 7 days of curing, the indirect tensile strength of CP20 was higher than that of CP, but as the age of curing increases, the indirect tensile strength of CP and CP20 tends to be similar. The reduction in the indirect tensile strength was less than for the compressive strength of the concrete. This is because as the tyre rubber particle is softer material than the aggregate, it can acts as a barrier to the growth of crack in the concrete. Tang *et al.*, (2012) investigated the properties of concrete containing scrap tyre, they observe that both the compressive and tensile strengths of concrete decreased with an increase in chipped tyre content. However, the reduction in compressive strength was relatively greater than its tensile strength. The possible reason might be the tyre rubber as a soft material can act as a barrier against crack growth in concrete. Also, they found that by increasing the proportion and size of chipped tyres, the failure observed in the cube compression test was more compressible with less crack lines and the specimens were capable of retaining the load after failure without extensive disintegration, in comparison with the brittle failure of control concrete. Sooraj (2013) carried out a similar report on POFA. He found that the indirect tensile strength test results of palm oil fuel ash concrete for the 28 day strength with increment of POFA from 0% to 10%. However, for 20% ash added, the tensile-strength development was the same as the control samples. When he increased the replacement of POFA to 30%, strength decreases.

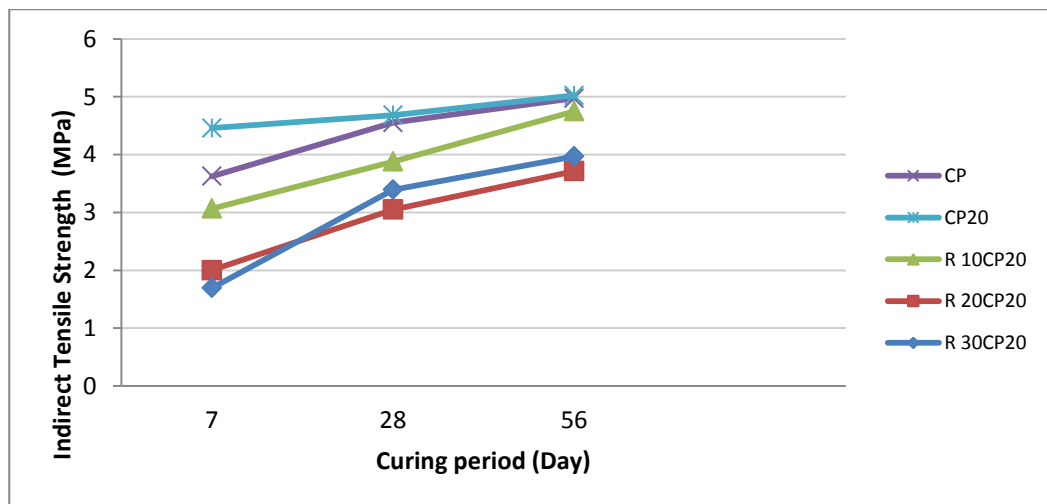


Figure 4: Variation of Indirect tensile strength with time

4.0 Conclusions

In this research the performance of concrete containing 20% POFA as OPC replacement was analysed. The performance of 20% POFA concrete, with fine aggregate partially replaced by 10%, 20% and 30% tyre rubber particles were also analysed. The following conclusions were drawn based on experimental results.

- i) Replacing fine aggregate by 10%, 20% and 30% rubber particles in concrete containing 20% POFA results in decrease in compressive strength, although the decrease was less than when the fine aggregate was replaced with rubber particles in normal ordinary cement concrete
- ii) As for the flexural strength, replacing the fine aggregate by 10%, 20% and 30% rubber particles decreases the flexural strength as compared with CP and CP20. But as the percentage of replacement is increased, the flexural strength increases.
- iii) As for the indirect tensile strength, replacing the fine aggregate by 10%, 20% and 30% rubber particles decreases the indirect strength. As the percentage replacement increases, the indirect tensile strength also decreases. However, for 20% replacement of fine aggregate in 20% POFA concrete, (R20C20), the 7 days and 28 days indirect tensile strength were found to increase.
- iv) The 28 days compressive strength of CP20 which contained 20% POFA is higher than the control by 3.7%, that is to say 20% POFA increases the compressive strength.
- v) The indirect tensile strength of CP20 is higher than that of the control, and the flexural strength of CP20 is lower than that of the control. However, at the early age of 7 days, the flexural strength of CP20 is similar to that of the control.

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