The effect of polymer coated pumice to the stiffness and flexural strength of reinforce concrete beam

Indradi Wijatmiko[1,*], *Ari* Wibowo[1], and *Christin* Remayanti[1]

[1]Department of Civil Engineering, Faculty of Engineering, Universitas Brawijaya, Malang 65149, Indonesia

Abstract. Pumice has been proven as substitution material aggregate in lightweight aggregate concrete (LWAC). However due to its characteristic, pumice has the disadvantages of its excessive water absorption during preparation of concrete mixture which may reduce concrete strength. Therefore in order to eliminate this additional water absorption, this study investigate the effect of coated pumice in concrete mixture to the beam flexural strength and stiffness. This study performed flexural strength test on three types of sample: 1) normal reinforce concrete beam, 2) reinforce concrete beam with uncoated pumice and 3) reinforce concrete beam with coated pumice. The result showed that the lightest weight concrete occurred on the coated pumice specimen, with the reduction of water absorption was 4% compared to the uncoated pumice specimen. The stiffness of the reinforce beam with coated pumice was lower compared to the uncoated ones, this was due to the reduction of adhesion action between cement and aggregates. However, the use of coated pumice increased the flexural strength compare to the uncoated ones with 2.58%.

1. Introduction

LWAC has been known offers various advantages due to its lower density [1], higher ratio of strength/weight [2], less conductivity thermal [3,4], better durability properties [5,6], fire resistance [7] and etc. The use of lightweight concrete reduce the size of columns, beams, wall and foundation which as well reducing the dead load and minimizing the damages of structures due to earthquake [8]. The idea of LWAC is to substitute a whole or part of normal weight concrete (NWC) by a natural or synthetic lightweight materials. In Indonesia, which known also as volcanic country, pumices are enormously found in most part of country as a result of solidification of lava with the release of volcanic gases at the same time. Pumice has a porous structure which is formed due to trapped bubbles and interconnected to each other. Further, this character consequential produce lesser weight and low coefficient of thermal expansion to the concrete mixture. However, the created void causes the disintegration in concrete due to prior water absorption and the risk of flocculation during concrete pouring [9,10].

Comprehensive researches has been conducted over the last few years on the use of pumice lightweight aggregate either in structural lightweight concrete production or lightweight concrete implemented for thermal insulation and masonry blocks [11-14]. However only a few research has been conducted to overcome the disintegration concrete due to the excessive water absorption.

Polymer has long chains molecular structure which lead to the strong bonds. Polymer easily processed and commonly produce in oil-based synthetic form such as paint. One of its advantages, which is building block of basic materials, e.g. water, may becoming the solution on the prior water absorption by pumice. As the prior water absorption can be reduced, the weight of concrete becomes lighter, thus the mechanical properties of applied coated pumice as coarse aggregate yet to be discussed.

Therefore this study investigate the effect of polymer coated pumice on LWAC to its flexural strength and stiffness through series of experiments. This study compare the normal weight concrete as a control specimens with the polymer coated and uncoated pumice mixtures as coarse replacement in concrete.

2. Experimental details

To investigate the effect of polymer coated pumice to the stiffness and flexural strength of reinforce concrete beam, nine mixtures with varying volume and coating of pumice were prepared.

* Corresponding author: indradi@ub.ac.id

2.1 Material properties

Pumice aggregate was obtained from Kediri residency of Indonesia. It has been reported that part of the quality of the reserve are good, while other required to be washed for quality improvement. Coated pumice were applied by dipping a group of grain aggregate 8-16 mm into a polymer liquid. The coated pumice then dried at the room temperature 25 ± 2 °C for 24 hours.

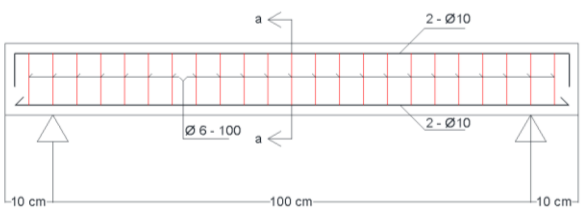
The cement used in all mixes was ordinary Portland cement type 1, which corresponds to ASTM type 1. The fine aggregate of local river sand and tap water were used for all mixtures. The properties of aggregates can be seen in Table 1, which shows the specific gravity of coated pumice is lower than uncoated pumice, as well as its water absorption ability.

Table 1. Properties of aggregates

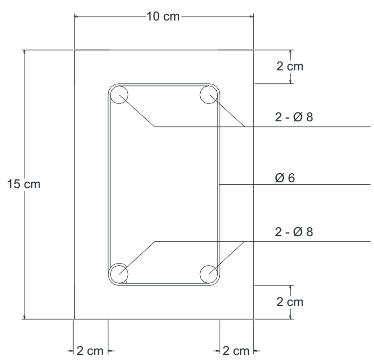
Aggregates	Specific gravity	Bulk density (kg/m^3) ASTM		Water absorption 24h (%)
	Ovendry	Shoveled Ovendry	Rodded Ovendry	
Coarse aggregate the				
GA	2.67	2696	2589	3.20
PA	1.85	-	-	14
CPA	1.79	-	-	10
Fine aggregate				
River sand	2.60	2530	2693	3.22

GA:Gravel Aggregate ; PA;Pumice Aggregate ; CPA : Coated Pumice Aggregate

2.2 Specimen and testing



(a)



(b)

Fig. 1. (a) Specimen long section layout , (b) a-a section layout

Nine mixtures of reinforce concrete beam, consist of three normal weight concrete, three lightweight uncoated pumice aggregate concrete and three lightweight coated pumice aggregate concrete. As can be seen in figure 1a, each beam, with the dimension of 120 cm length, 10 cm width and 15 cm height, were subjected to be tested for flexural strength.

3. Result and discussion

3.1 Density and workability

As shown in Table 1, coated pumice with polymer is resulting to the decreasing of water absorption. And as consequence, the weight of a specimen also reduced. Therefore, the density of the concrete with coated pumice is the lowest due to the reduction of weight as shown in Table 2.

The workability of concrete is described to understand the effect of pumice aggregate character as coarse aggregate. Table 2 present the properties of aggregate and mix design. As a LWAC, which has lower aggregate density and produce lighter mix. Further, it is common for LWAC to have lower slump value, as confirmed from some research studies [15,16] and recommend in ACI 213R-87. LWAC coated pumice produced lowest slump value due to the lower weight as a result of water absorption reduction. Though the LWAC pumice and LWAC coated pumice has lower slump value, the workability are remain at the same stage as NWC. And in order to maintain the cohesive and avert the segregation, a higher slump value is demanded with the additional effort to preserve the ideal surface of specimens.

Table 2. Properties of mix design

Mix ID	Density (kg/cm^3)	Slump (cm)
NWC		14.5
NWC-1	2447	
NWC-2	2557	
NWC-3	2533	
LWAC : Pumice		12.2
PC-1	2169	
PC-2	2130	
PC-3	2102	
LWAC : Coated Pumice		10.8
CPC-1	2100	
CPC-2	2097	
CPC-3	2080	

NWC: Normal Weight Concrete; LWAC: Lightweight Aggregate Concrete

3.2 Compressive strength

Compressive strength test (refer to Figure 2) were conducted for 3 cylindrical specimens with 8 cm diameter and 16 cm height at the age of 28-day, as seen in Table 3.

The substitution of strong gravel aggregate by relatively weak pumice aggregate cause the decrease of compressive strength at 28-day. Further, the introduction of coated polymer on pumice resulting minor reduction in compressive strength.

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Table 3. Compressive strength (28-day)

Mix ID	Density (kg/cm^3)	Max. Load (kg)	f'_c (MPa)
NWC	2177	89	17.71
LWAC: Pumice	1866	64	12.74
LWAC: Coated Pumice	1990	59	11.74

Fig. 2. Compressive strength test

Reduction in compressive strength of pumice aggregate concrete can be attributed by the lack of clinker (C_3S), which resulting on slowing the hydration and decreasing the rate of heat development, especially when the polymer coat were applied. However, due to ongoing pozzolanic reaction, the differences becomes smaller in long period. It is related with the total content of silicon dioxide in pumice that can form compound with cementitious properties [17].

3.3 Flexural strength

Flexural strength test were subjected to nine reinforce beam with three categories, i.e. normal weight concrete, lightweight concrete with uncoated pumice aggregate and lightweight concrete with coated pumice aggregate. The experimental test setup in Figure 3 shows there were 2 LVST installed for subsequent readings during the applied force-controlled.

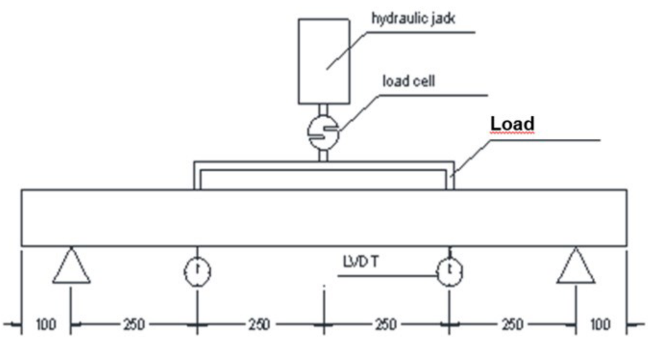
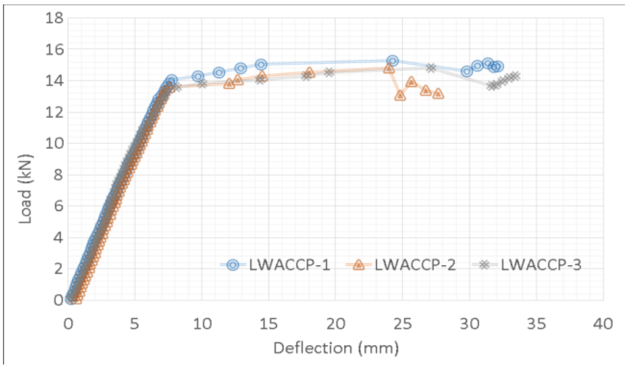
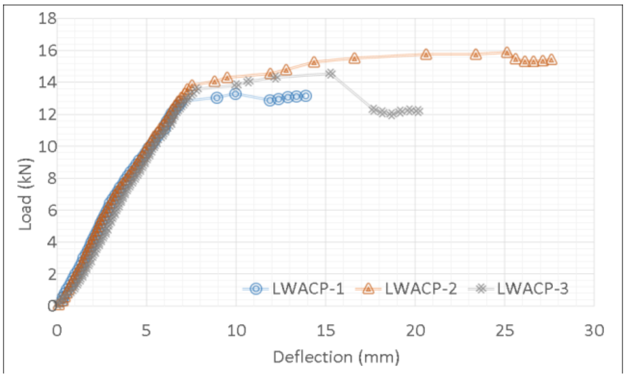


Fig. 3. Flexural strength test

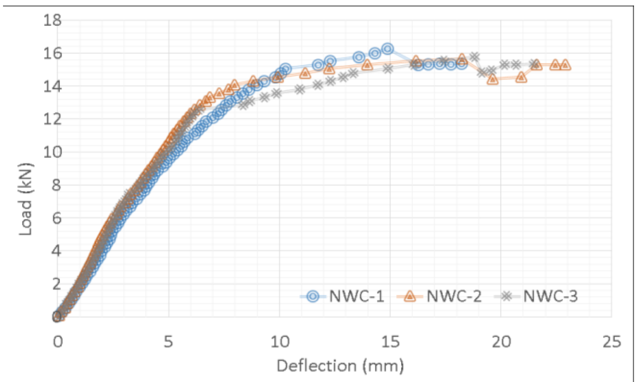
The result of flexural strength test can be seen in Figure 4a, 4b, and 4c respectively for normal weight concrete, pumice aggregate concrete and coated pumice aggregate concrete.



(a) Load-deflection behavior for specimens of normal weight concrete



(b) Load-deflection behavior for specimens of lightweight aggregate concrete with pumice



(c) Load-deflection behavior for specimens of lightweight aggregate concrete with coated pumice

Fig. 4. Detail of load-deflection behavior of specimens

Among specimens, the peak load of NWCs were higher compare with the LWACPs. The average peak load of NWC was 31.8 kN, while the LWAC with uncoated pumice had 29.2 kN and the LWAC with coated pumice had 29.93 kN. Thus with the same testing behavior and parameter, the flexural strength of NWC had similar result as the peak load. Interestingly, the application of polymer coating to the pumice increase the flexural strength up to 2.58 %, as indicated from the average flexural strength in Table 4.

Table 4. Flexural strength

Mix ID	Pu (kN)	Flexural Strength (kN.m)	Average Flexural Strength (kN.m)
NWC			
NWC-1	32.5	4.06	3.97
NWC-2	31.3	3.91	
NWC-3	31.6	3.94	
LWAC: Pumice			
LWACP-1	26.7	3.33	3.64
LWACP-2	31.8	3.97	
LWACP-3	29.1	3.64	
LWAC: Coated Pumice			
LWACCP-1	30.6	3.82	3.74
LWACCP-2	29.6	3.70	
LWACCP-3	29.6	3.70	

The idea of flexural strength is to determine the distribution of the stress and strain distribution of concrete. At the ultimate stage, the unconstrained concrete is assumed fail when it reach the compressive strain limit. The ultimate compressive has been determined by assuming a constant value i.e. 0.003 (ACI 318) or 0.0035 (BS 8110), however these value will be conservative for NWC but will be un-conservative for high strength LWAC due to the decreasing of ultimate compressive strain capacity of unconfined LWAC as a result of increasing concrete strength.

3.4 Stiffness

As seen in Figure 5, all type of specimens share similar initial stiffness. LWACCP showed the higher value of stiffness compare to the NWC and LWACP.

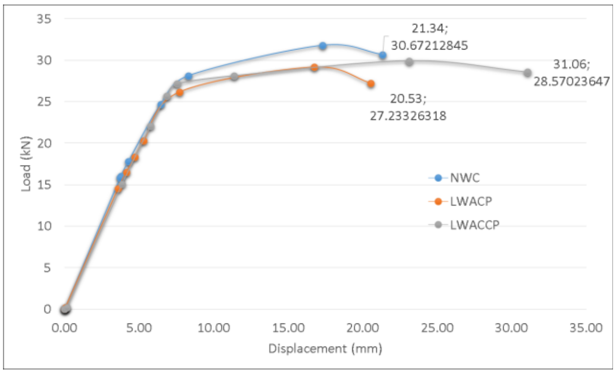


Fig. 5. Detail of load-deflection behavior of three category of specimens

Cracking reduce the beam stiffness, therefore to calculate the beam stiffness the subjected load is taken before the first crack occurred. From the observation, the first crack of NWC occurred by 15.86 kN load, while the uncoated and coated pumice had the first crack at 16.52 kN and 22.8 kN respectively.

Though the coated pumice was able to increase the flexural strength, the stiffness of coated pumice was lower than the uncoated ones. This is the due to the reduction of adhesion action between cement and aggregates

Table 5. Stiffness of specimen

Mix ID	Load (kN)	Stiffness
NWC	15.37	4.26
LWACP	15.37	4.02
LWACCP	15.37	3.89

4 Conclusions

Nine reinforce concrete beams were investigated to have a clear understanding of the effect polymer coated pumice as coarse aggregate to the flexural strength as well as its stiffness. In order to get stronger observation, three types of concrete were studied, i.e. normal weight concrete, lightweight pumice concrete and lightweight coated pumice concrete. Several outcomes can be observed as follows:

1. The Polymer coated was proven to reduce the water absorption of pumice. And as consequence, it lighter the concrete weight and reduce the density. The coated pumice has lower slump value, yet the workability still at the high stages as NWC.
2. The compressive strength of pumice mixtures on LWAC were lower than NWC, due to the lack of clinker. However, the differences becomes smaller in long period due to the content of silicon dioxide in pumice which can form compound with cementitious.
3. The flexural strength of coated pumice was slightly higher than uncoated ones. However, the coated pumice had lower stiffness characteristic due to the reduction of adhesion action between cement and aggregates

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