

High Strength Lightweight Aggregate Concrete using Blended Coarse Lightweight Aggregate Origin from Palm Oil Industry

(Konkrit Agregat Ringan Kekuatan Tinggi menggunakan Gabungan Kasar Ringan
Agregat Asal daripada Industri Minyak Sawit)

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ABSTRACT

The benefits of using structural lightweight concrete in construction industry, particularly in high rise buildings, over normal weight concrete are numerous. The main method of producing structural lightweight concrete is the use of lightweight aggregates instead of ordinary aggregates in concrete. Due to the limited resources for natural and artificial lightweight aggregates, the alternative sources for lightweight aggregates should be discovered from industrial wastes. Oil palm shell (OPS) and oil-palm-boiler clinker (OPBC) are two solid wastes from palm oil industry and are available in abundance in tropical regimes. The use of just OPS as coarse lightweight aggregate in concrete mixture has some drawbacks for concrete. The aim of this study was to investigate engineering properties of a lightweight concrete containing both of these aggregates. For this purpose, in this study, 50% (by volume) of OPS was replaced with OPBC in an OPS lightweight concrete. The test results showed that when OPS was substituted with OPBC, significant improvement was observed in the compressive, splitting tensile and flexural strengths. In addition, initial and final water absorption as well as drying shrinkage strain of blended coarse lightweight aggregate concrete were significantly less than OPS concrete.

Keywords: Clinker; drying shrinkage; lightweight aggregate; mechanical properties; oil palm shell

ABSTRAK

Terdapat banyak faedah menggunakan struktur konkrit ringan dalam industri pembinaan, terutamanya pada bangunan tinggi, berbanding konkrit biasa. Kaedah utama menghasilkan struktur konkrit ringan adalah penggunaan agregat ringan dan bukannya biasa agregat dalam konkrit. Oleh kerana sumber yang terhad untuk agregat ringan yang asli dan tiruan, sumber alternatif untuk agregat ringan harus diterokai daripada sisa industri. Tempurung kelapa sawit (OPS) dan klinker dandang kelapa-sawit (OPBC) adalah dua sisa pepejal daripada industri minyak sawit dan didapati dengan banyaknya dalam rejim tropika. Penggunaan OPS sahaja sebagai agregat ringan kasar dalam campuran konkrit mempunyai beberapa kelemahan untuk konkrit. Tujuan kajian ini adalah untuk mengkaji sifat kejuruteraan konkrit ringan yang mengandungi kedua-dua agregat ini. Bagi tujuan kajian ini, 50% (isi padu) daripada OPS telah digantikan dengan OPBC untuk konkrit ringan OPS. Keputusan ujian menunjukkan apabila OPS digantikan dengan OPBC, peningkatan ketara diperhatikan di dalam mampatan, pemecahbelahan tegangan dan kekuatan lenturan. Di samping itu, serapan awal dan akhir air serta strain pengecutan kering konkrit campuran kasar agregat ringan adalah jauh berkurangan daripada konkrit OPS.

Kata kunci: Agregat ringan; klinker; pengecutan kering; sifat mekanik; tempurung kelapa sawit

INTRODUCTION

The concrete industry nowadays is the largest consumer of natural resources due to its widely usage in civil engineering structures. Its annually consumption of materials is as 2.282 billion tonnes of cement, 10-12 billion tonnes of stones and rocks together and 1 billion tonne of mixing water (Chuan 2015; Mehta & Monteiro 2006). Due to huge amount of concrete production, it has a significant effect on the social, economic and environmental problems (Pelisser et al. 2012; Sari et al. 2015; Tam 2009). The best alternative to achieve an environmentally friendly and sustainability in concrete industry is to use waste and by-product materials instead of raw materials in concrete mixtures, which

can contribute to a better quality of life for all mankind (Aslam et al. 2015; Shafigh et al. 2012a).

Lightweight concrete (LWC) is a most interesting field of research and has been widely used in buildings since ancient times. It has many advantages such as better heat insulation, sound absorption, fire and frost resistance and increased seismic damping (Aslam et al. 2016a; Shafigh et al. 2010). High strength lightweight concrete can be produced up to grade 60 with an oven dry density range of about 350-2000 kg/m³ (Shafigh et al. 2010). A study (Sari & Pasamehmetoglu 2005) showed that the NWC has a low strength to weight ratio and its use in structural members such as multi story buildings, bridges and floating structures is a huge economic disadvantage. Therefore,

the best way to resolve this issue is to use high strength lightweight concrete (HSLWC). It can also reduce the dead load of the structures by reducing the cross sections of beams, columns and foundations (Yasar et al. 2004).

The most popular method of fabricating LWC is by using lightweight aggregate (LWA) (Polat et al. 2010). Since the last few decades many types of lightweight aggregate such as foamed slag, volcanic cinders, diatomite, expanded clay, tuff, scoria, shale, slate, vermiculite, perlite and materials occurred as industrial by-products such as sintered slate, pulverized-fuel ash and expanded blast-furnace slag has been used as construction material (CEB/FIP 1977; Neville 2008; Shafiqh et al. 2014a). The artificial LWAs were produced by the application of high temperature and pressure, which results in high fuel costs (Shafiqh et al. 2010). Therefore, the best alternative source for LWAs is the utilization of waste materials, which significantly reduces the construction costs as well as has many benefits in environmental issues. Oil palm shell (OPS) and oil-palm-boiler clinker (OPBC) are an alternative waste materials found in tropical regime countries and can be used as aggregate in concretes. It was found that Malaysia alone annually produced more than 4 million tonnes of OPS, very small amount of this solid waste is used as a fuel in oil palm mills (Sobuz 2014). Previous studies (Hilmi et al. 2014; Mannan & Neglo 2010) showed that OPS and OPBC can be used as coarse aggregate to produce green and sustainable structural lightweight aggregate concrete. The densities of both aggregates were also found in the suitable range of structural lightweight aggregates. Recent studies (Aslam et al. 2015; Shafiqh et al. 2014a) have showed that the OPS and OPBC can be used as lightweight aggregate to produce high strength lightweight concrete.

Substitution of normal aggregates with OPS in normal weight concrete reduces its mechanical properties and increases water absorption of concrete (Shafiqh et al. 2012b). A lightweight concrete containing OPS has high drying shrinkage (Abdullah 1996; Mannan & Ganapathy 2002; Shafiqh et al. 2014b). This concrete should have very well moist cured, otherwise it may have significant reduction on compressive strength (Mannan & Ganapathy 2002; Shafiqh et al. 2011). Higher volume OPS in concrete

mixture cause to be more sensitive to lack of curing. On the other hand, OPBC is a crushed porous stone which is produced by burning of agricultural solid wastes in the boiler combustion process in oil palm mills. Therefore, it is expected that by using of OPBC in OPS concrete and reduction of the amount of OPS aggregates the engineering properties of resulted concrete are improved. Therefore, the objective of this paper was to produce a new type of lightweight aggregate concrete using a blended coarse lightweight aggregate by incorporating OPS and OPBC in concrete mixture. In this study, the engineering properties of the developed lightweight aggregate concrete were investigated. The mechanical properties such as compressive, splitting tensile and flexural strengths and modulus of elasticity of OPS-OPBC concrete were measured. In addition, initial and final water absorptions as well as drying shrinkage strain of this blended coarse lightweight aggregate concrete were also investigated. The drying shrinkage strain results were also compared by the ACI-Standard model.

EXPERIMENTAL DETAILS

MATERIALS USED

Ordinary Portland cement (OPC) with specific gravity of 3.14 and 28-day compressive strength of 48 MPa was used as binder. The OPS and OPBC were used as coarse aggregates (Figure 1). They were collected from a local palm oil mill then washed and dried in the laboratory. After drying, they were crushed using a crushing machine and sieved to achieve almost the same grading of the coarse aggregates (Figure 2). For both concrete mixes, the OPS and OPBC aggregates were weighed in dry condition and then immersed in water for 24 h. After that they were air dried in the lab environment for about 2 h to obtain aggregate with saturated surface dry condition.

The physical and mechanical properties of OPS and OPBC are shown in Table 1. As can be seen from Table 1, OPBC has higher density but it has significantly lower water absorption compared to OPS aggregate. Local mining sand with a specific gravity of 2.68 and maximum grain size of 4.75 mm was used as fine aggregate. The super-plasticizer



FIGURE 1. Oil palm shell (left) and oil-palm-boiler clinker (right)

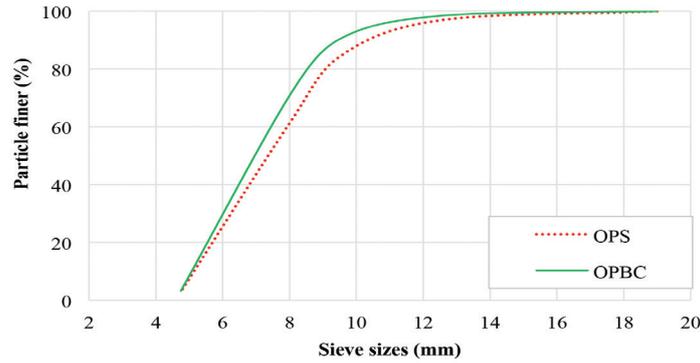


FIGURE 2. Grading of OPS and OPBC aggregates

TABLE 1. Physical and mechanical properties of lightweight aggregates

Physical and mechanical properties	OPBC	OPS
Specific gravity (saturated surface dry)	1.69	1.19
Compacted bulk density (kg/m ³)	860	610
24 h water absorption (%)	7.0	20.5
Abrasion value (%)	23.9	5.7
Crushing value (%)	21.2	0.2
Impact value (%)	36.3	5.5

(SP) was selected according to ASTM C494-86 Type G with a density of $1.09 \pm 0.02 \text{ kg/m}^3$.

MIX PROPORTIONS AND PROCEDURE

Concrete containing only OPS as coarse lightweight aggregate was considered as the control mix and in the other mix, 50% of volume of OPS was replaced with OPBC. The cement content and aggregates volume were placed constant for both mixes but the water content for OPS-OPBC mixture was reduced. The main reason for the reduction of water to cement ratio was to control the slump value of the concrete to maintain similar to slump of control OPS concrete. The mix proportions of both mixes are shown in Table 2.

For mixing, the cement and aggregates were placed into a mixer and mixed for 2 min. Subsequently, the mixture of SP and 70% of mixing water were added to the mixture and mixing was continued for another 3 min. After that, the remaining water was added to the mixture and mixing was continued for another 5 min. Then the workability by performing the slump test was evaluated. Fresh concrete was then cast into 100 mm cube steel moulds for compressive strength, cylinders

of 100 mm diameter and 200 mm height for splitting tensile strength, cylinders of 150 mm diameter and 300 mm height for elastic modulus, prisms of $100 \times 100 \times 500 \text{ mm}^3$ for flexural strength and prisms of $100 \times 100 \times 300 \text{ mm}^3$ for drying shrinkage strain tests. Specimens were compacted using a vibrating table in the laboratory with the temperature of $30 \pm 2^\circ\text{C}$ and relative humidity of about 70%. The specimens were demoulded after 24 h of casting and were immersed in water at the temperature of $24 \pm 2^\circ\text{C}$. Three test specimens were prepared to obtain the average values of the mechanical properties at any age. The drying shrinkage specimens were kept under 7 days moist curing, after that shrinkage readings were recorded under laboratory environment condition.

RESULTS AND DISCUSSION

WORKABILITY AND DENSITY

Table 3 shows the slump value and density of the concrete mixes. It was observed that both OPSC and OPBCC mix showed similar and satisfactory workability. As can be seen in Table 2, the water to cement ratio of OPBCC is significantly less than OPSC, while their workability was

TABLE 2. Mix proportions for concretes

Mix code	Content (kg/m ³)					w/c ratio	SP (% cement)
	OPC	Water	Sand	OPS	OPBC		
OPSC	480	173	890	360	0	0.36	1
OPBCC	480	139	890	180	256	0.29	1

similar. This is due to the shape and physical properties of OPBC aggregate. Compared to OPS aggregates, OPBC aggregate is circular in shape and has lower water absorption of about 66%, therefore at the same mix proportions concrete containing OPBC has higher slump value compared to OPS concrete (Aslam et al. 2016b). For this reason, to keep constant similar slump value water content in OPBCC was reduced. According to Mehta and Monteiro (2006), structural lightweight aggregate concrete with a slump value in the range of 50 to 75 mm is considered as a LWC with good workability. At the same workability, concrete containing 50% coarse OPBC aggregates has about 20% lower water to cement ratio. This significant reduction in water to cement ratio may significantly affect hardened properties of the concrete.

Table 3 shows that concrete containing OPBC aggregate is heavier than OPS concrete. This is due to the density of OPBC is more than OPS. However, it should be noted that, although the incorporation of OPBC in OPS concrete increased the density, however, the density of OPBC concrete is still in the acceptable range for the structural lightweight concrete.

COMPRESSIVE STRENGTH

The development of compressive strength of OPSC and OPBCC mixes under continuous moist curing up to age of 56 days is shown in Figure. 3. It was observed that both mixes showed similarly sharp gain in compressive strengths at early ages. The OPBCC mix has showed higher compressive strengths of about 25.9%, 28.1%, 28.4%, 30.7% and 28.9% at 1, 3, 7, 28 and 56 days, respectively, compared to the

control OPS concrete. The OPSC and OPBCC mixes showed a significant difference between the compressive strength results. The compressive strength of control OPS concrete showed a 11.4%, 16.8% and 20.2% increase at 7, 28 and 56 days, respectively, as compared to 3-days strength, while, these ratios for OPBCC mix are 11.7%, 19.8% and 21.2%, respectively. Consequently, the OPBC concrete mixture showed higher rate of strength gain up to 28-days but at later ages this rate was lower when compared to OPSC mix.

The OPBCC mixture showed 28-day compressive strength of about 53.3 MPa, which is about 30.7% higher than the control OPS concrete. The key problem in OPS concrete is due to it includes many shapes such as roughly parabolic, flaky and irregular with smooth surface texture. OPBCC showed higher compressive strength due to: OPBC aggregates are not flakey; They have rough surfaces which improve interlocking between cement matrix and aggregate; The density of OPBC aggregate is higher than OPS aggregate and therefore, reduction of OPS and increase the OPBC content improved the compressive strength of concrete; and it was found that due to round shape of OPBC grains, substitution of OPS with OPBC improved the workability of concrete. Therefore, for the same workability, the water to cement ratio in OPBCC could be reduced. The lower water to cement ratio increased the compressive strength.

Lo et al. (2004) reported that strength of LWC depends on the properties of the aggregates used and the hardened cement paste and their interfacial bonding. Okpala (1990) reported that the failure of OPS concrete dependent upon the breakdown of the bond between the shell and the cement paste. Mannan et al. (2006) stated that the OPS concrete

TABLE 3. Slump and density

Mix code	Slump (mm)	Density (kg/m ³)	
		Demoulded	Oven dry
OPSC	55	1920	1790
OPBCC	52	2015	1940

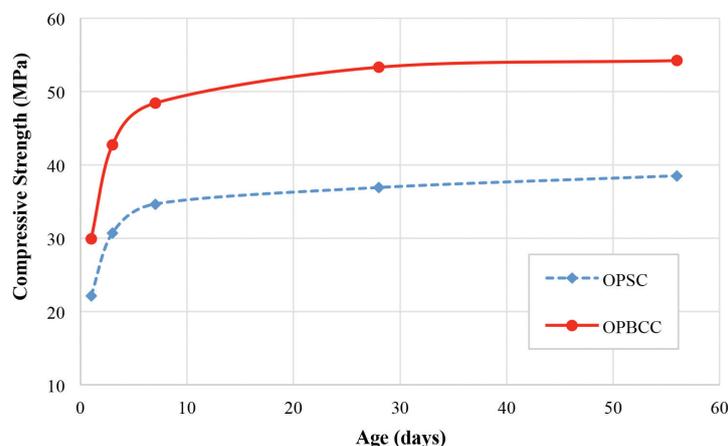


FIGURE 3. Development of compressive strength

was generally failed due to the adhesion between the shell and the cement paste. Further, they improved the quality of the shells using pre-treatment methods and achieved the 28-day compressive strength of about 33 MPa.

From 28 days compressive strength results it can be seen that the replacement of OPS by 50% OPBC in second mix highly increases the compressive strength from grade 35 to grade 50 which can be consider as high strength lightweight aggregate concrete. The major reason to show higher compressive strength in OPBCC is due to this concrete has significantly lower water to cement ratio as compared to OPS concrete. Therefore, it is expected that this aggregate has better interlock with cement matrix and consequently higher compressive strength.

SPLITTING TENSILE AND FLEXURAL STRENGTHS

ASTM-C330 (2005) specified that the minimum 28-day splitting tensile strength required for structural LWAC must be 2.0 MPa. As can be seen in Table 4, both mixes showed significantly higher splitting tensile strength (39% for OPSC and 44% for OPBCC) than the minimum requirement of ASTM-C330 (2005). Generally, the splitting tensile strength of the concretes is proportional to its compressive strength, the higher the compressive strength higher will be the splitting tensile strength. Literature (Abdullah 1996; Alengaram et al. 2008; Mannan & Ganapathy 2002) showed that under standard curing, the OPS concrete showed the 28-day splitting tensile strength in the range of 1.10-2.41 MPa. As can be seen in Table 4, in this study, OPS concrete showed significantly higher splitting tensile strength compared to previous studies. However, in the mix OPBCC, the replacement of OPS aggregate by 50% OPBC aggregate improved the splitting tensile strength at all ages. It is interesting to note that a significant improvement from 7 to 28 days for the splitting tensile strength of the OPBCC mix was observed, while for OPS concrete the improvement was small. Normally, the ratio of splitting tensile to compressive strength of NWC was found in the range of 8-14% (Shafiq et al. 2014c). However, this ratio for OPS and OPBC concretes is about 9% and 6.7%, respectively. This ratio for OPS concrete was in the range of NWCs, however, this ratio for OPBCC was lower than the minimum value of 8%. This is due to OPBCC is a high strength concrete. In high strength LWC, this ratio is in the range of 6-7% (Holm & Bremner 2000).

The flexural strength of OPSC and OPBCC mixes at 7- and 28 days are shown in Table 4. It was observed that similar to compressive and splitting tensile strengths,

the flexural strength of OPBCC mix is also higher than OPS control mixture. In order, the OPBCC mix showed the compressive, splitting tensile and flexural strengths of about 31%, 23% and 8% higher than the control OPS concrete, respectively. Mehta and Monteiro (2006) reported that the flexural strength of NWC with a compressive strength of 34-55 MPa is in the range of 5-6 MPa, with flexural to compressive strength ratio of about 11.6-13.5%. However, the flexural to compressive strength ratio of high strength LWAC was generally varies in the range of 9-11% (Holm & Bremner 2000). The 28-day flexural to compressive strength ratio of OPSC and OPBCC mixes was about 14.6% and 13.2%, respectively. The flexural to compressive strength ratio of OPBCC mix is similar to NWC and greater than high strength LWAC.

MODULUS OF ELASTICITY

The modulus of elasticity plays very important role in civil engineering structures. It measures the material resistance to the axial deformation. It represents the maximum allowable stress limit of that material before undergoing the permanent deformation. Its value is obtained by measuring the slope of the axial stress-strain curve in the elastic region (Malesev et al. 2014). It was reported that the modulus of elasticity for structural lightweight concrete is 17-28 GPa while it is 20-40 GPa for normal weight concrete (Holm & Bremner 2000). The modulus of elasticity of the OPSC and OPBCC mixes were 7.9 and 15.7, respectively. The OPS concrete was considered as a concrete with low elastic modulus, while the replacement of OPS by 50% OPBC aggregates significantly increased the modulus of elasticity by about 50%. Neville (1971) reported that the modulus of elasticity of concrete depends on the moduli of elasticity of its components and their proportions by volume in the concrete. Kosmatka et al. (2002) stated that the modulus of elasticity of NWC ranges between 14 and 41 GPa, while, in LWC, it ranges from 10 to 24 GPa. The test results of this study showed that the modulus of elasticity of OPS concrete containing OPBC aggregates was in the range for NWC as well as structural lightweight aggregate concretes.

WATER ABSORPTION

The results of initial (30 min) and final (72 h) water absorptions are shown in Figure 4. CEB-FIP (Ranjbar 2013) categorized concrete quality as poor, average and good for initial water absorption values of 5% and above, 3-5% and 0-3%, respectively. Both concrete mixes showed an initial water absorption of less than 3% which can be

TABLE 4. Splitting tensile and flexural strengths

Mix code	Splitting tensile strength (MPa)				Flexural strength (MPa)	
	1 day	3 days	7 days	28 days	7 days	28 days
OPSC	2.20	2.89	3.03	3.29	4.43	5.38
OPBCC	2.59	3.00	3.25	3.58	5.15	7.00

categorized as ‘good’ quality concrete. Incorporating of OPBC in OPS concrete could reduce initial water absorption of OPS concrete about 45%. Final water absorption of OPBCC was about 42% less than OPSC. The reduction of water absorption is due to the lower water absorption of the OPBC aggregates compared to OPS aggregates (Table 1). Generally, the OPS concretes with normal compressive strengths showed water absorption higher than 10% (Teo et al. 2007). Neville (2008) reported that although the concrete quality cannot be predicted by the absorption of water, however in general, good concretes has water absorption of less than 10% by mass. On the other hand, there is this believe that in most cases good concretes have final water absorption less than 5% (Kosmatka 2002). By considering all the criteria’s in water absorption of concrete, test results of this study show that OPBCC can be considered as good quality concrete.

DRYING SHRINKAGE

The development of the drying shrinkage strain of the lightweight concretes (OPSC & OPBCC) after 7 days moist curing for up to about 8 months are showed in Figure 5. As can be seen in the figure, there is a significant difference between the shrinkage results of the both mixes. The control mixture (OPSC) showed the highest drying shrinkage strain of about 614 mm/mm which is about 36% higher than the OPBCC mixture. This shows that the substitution of OPS with OPBC aggregates has a significant influence on the drying shrinkage strain. Aslam et al. (2016c) investigated the drying shrinkage behaviour of structural lightweight aggregate concrete using blended oil palm bio-products. They reported that 7-day moist cured concretes containing both types of OPS and OPBC aggregates have lower drying shrinkage compared to structural lightweight aggregate concretes were made of lightweight aggregates such as lytag, expanded shale or sintered fly ash. Al-Khaiyat and Haque (1998) investigated the long-term drying shrinkage performance of lytag lightweight aggregate concrete

after 7 days moist curing. In their study, the drying shrinkage of about 640 micro strain was achieved at the age of 3 months. They have reported that various types of lightweight aggregate usually resulted different behaviour in drying shrinkage. Further, a lightweight concretes made of expanded clay and expanded shale aggregates with the compressive strengths of 30-50 MPa showed a drying shrinkage strain in the range of 400-600 micro-strain (CEB/FIP 1977).

The drying shrinkage strain of the OPS concrete was significantly reduced might be due to the following reasons. (1) OPS is an agricultural waste with smooth surface texture and has lower specific surface area, while the OPBC is a porous crushed stone so it is expected that the drying shrinkage of OPS is higher than OPBC aggregate. Al-Attar (2008) investigated the shrinkage strain of NWC by using crushed and uncrushed gravels as aggregates. He reported that the round uncrushed gravels have lower specific surface area and smoother texture due to that it showed higher drying shrinkage compared to crushed gravel aggregate concrete. Therefore, it can be seen that surface texture of aggregate influences the drying shrinkage of concrete. (2) It was observed that by the incorporation of the OPBC in OPS concrete, the all mechanical properties were improved. This is another reason that concrete with higher elastic modulus have lower drying shrinkage. This might be due to the strong interfacial bond between the OPBC aggregates and the cement paste. Neville (1977) reported that LWA usually leads to higher shrinkage in concrete due to its lower elastic modulus. In this study, the modulus of elasticity was highly improved by the contribution of the OPBC aggregate and was found in the range of normal weight concretes. (3) Another important reason of lower drying shrinkage strain of OPBC concrete was due to significant reduction of water to cement ratio from 0.36 to 0.29 in mix OPBCC. Bogas et al. (2014) reported that for the same cement content, the drying shrinkage strain increases with increasing water to cement ratio. In fact, there is an increment of the volume of paste

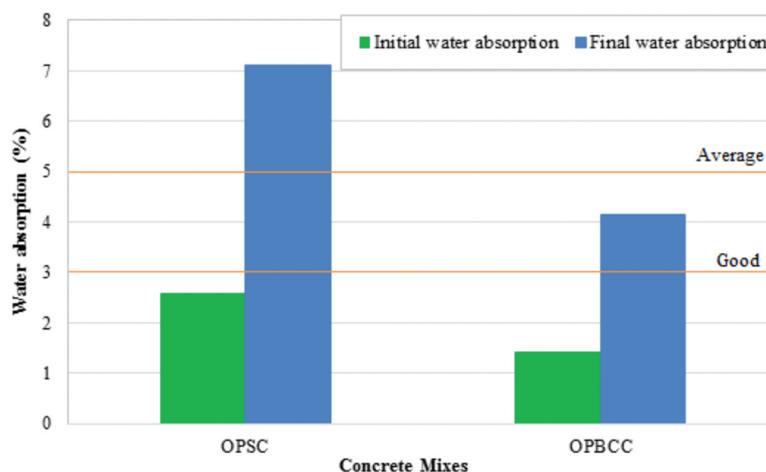


FIGURE 4. Water absorption of concrete mixes

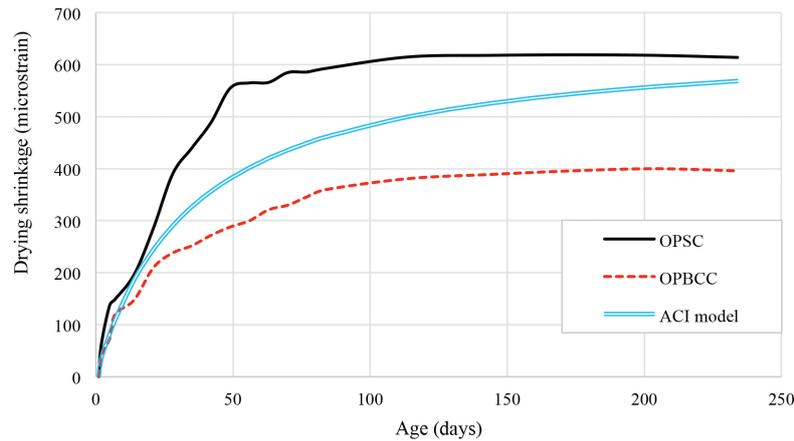


FIGURE 5. Drying shrinkage strain development of concretes

and a corresponding reduction of the aggregate content. The higher the water to cement ratio the lower the mortar stiffness and the higher the volume of evaporable water. A small reduction of the w/c ratio also causes a significant delay in drying shrinkage strain (Carlson 1938).

The experimental results of the drying shrinkage strain were also compared with the prediction model proposed by ACI-209R (2008). The ACI-209R (2008) proposed shrinkage prediction model as, $S_{(t, t_c)}$ at time t (days) measured from start of drying at t_c (days) and S_{∞} is the ultimate shrinkage.

$$S_{(t, t_c)} = \frac{(t - t_c)}{f + (t - t_c)} \times S_{\infty}, \quad (1)$$

$$f = 2.60 * e^{\left[1.42 * 10^{-2} \left(\frac{t_c}{s}\right)\right]}, \quad (2)$$

$$S_{\infty} = 780 \times 10^{-6} \times (Y_{sh}), \quad (3)$$

$$Y_{sh} = Y_{tc} \cdot Y_{RH} \cdot Y_{vs} \cdot Y_s \cdot Y_{\psi} \cdot Y_c \cdot Y_{\alpha}, \quad (4)$$

where, f is 35 for concrete water-cured for 7 days while to take into account the size and geometry on the drying of concrete specimens. Volume to surface area ratio is $\left(\frac{t_c}{s}\right)$ and Y_{sh} represents the product of several factors. Y_{tc} is the curing time coefficient, Y_{RH} is the relative humidity coefficient, Y_{vs} depends on volume to surface area ratio, Y_s is the slump factor (slump in mm), Y_{ψ} is the fine aggregate ratio (fine aggregate to the total aggregates), Y_c is the cement content in kg/m^3 and Y_{α} is the air content (%).

The ACI-209R (2008) prediction model of shrinkage strain gave close results to shrinkage values of both concretes up to one month. After one month, the drying shrinkage values from the model are closer to drying shrinkage of OPSC mix. In general, it can be concluded that this model code is suitable to predict drying shrinkage of OPS and OPS-OPBC concretes at short time (for up to one month) and for OPS concrete at later ages (for more than five months). Therefore, a new model code to predict drying shrinkage of OPS-OPBC concrete should be developed.

CONCLUSION

In this study, the mechanical and engineering properties of high strength lightweight aggregate concrete using blended coarse lightweight aggregates were investigated. From test results, the following conclusion can be drawn. Due to the round shape of OPBC aggregates, incorporation of this aggregate in OPS concrete improves workability of the concrete. Due to an OPBC grain is about 42% heavier than an OPS grain, inclusion of OPBC in OPS concrete increased the density of concrete. However, the density of OPS-OPBC concrete was still in the acceptable range for structural lightweight aggregate concretes. The substitution of 50% OPS with OPBC in OPS concrete the compressive, splitting tensile and flexural strengths significantly improved. By this substitution, grade 35 concrete with the oven dry density of about $1800 \text{ kg}/\text{m}^3$ was transferred to grade 50 concrete with the oven dry density of about $1950 \text{ kg}/\text{m}^3$. The modulus of elasticity of grade 35 OPS concrete is very low compared to normal concrete and structural lightweight aggregate concrete at the same compressive strength. However, the incorporation of OPBC in OPS concrete significantly enhanced this property. The modulus of elasticity of OPS-OPBC concrete is in the normal range of structural concretes. The initial and final water absorption of OPS-OPBC concrete is significantly less than OPS concrete. Based on water absorption, this concrete is considered as good quality concrete. The drying shrinkage of OPS and OPS-OPBC concretes is similar at early ages. However, OPS-OPBC concrete showed significantly lower drying shrinkage compared to OPS concrete after one month. The ACI-209R has conservative estimation for OPS-OPBC concrete.

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