American Journal of Applied Sciences 7 (12): 1572-1578, 2010
ISSN 1546-9239

Influences of Short Discrete Fibers in High Strength Concrete with Very Coarse Sand

[2]Mahyuddin Ramli and [1]Kwan Wai Hoe
[1]Department of Building Technology, School of Housing, Building and Planning
[2]University Sains Malaysia, Pulau Pinang, Malaysia

Abstract: Problem statement: High Strength Concrete (HSC) normally content high cementitous amount and low water binder ratio. However, these would cause substantial volume changes to the concrete and therefore affected the strength development. In addition, the brittleness of HSC was increased when silica fume used as partial cement replacement to achieve high strength. **Approach:** This study discussed the effects of incorporated short discrete Coconut Fibers (CF), Barchip Fibers (BF) and Glass Fibers (GF) into HSC to enhance the performance of concrete while kept the binder content at moderate level. Additional specialty to this HSC was casted with very coarse sand with fineness modulus of 3.98. A total of thirteen mixes were casted and tested for slump, density, compressive strength, flexural strength and ultrasonic pulse velocity in accordance with British Standards. **Results:** The slump was slightly reduced by the short discrete fibers. All of the fibrous specimens had lower density than control. However, the compressive strength of the HSC had increased from 71.8-79.0 MPa using 1.8% of BF, while flexural strength had increased from 5.21-6.50 MPa. All specimens showed that ultrasonic velocity higher than 4.28 km sec^{-1}. **Conclusion/Recommendations:** In short, combination of incorporated short discrete fibers and applied very coarse sand to produce HSC showed very satisfying results and improvements. Further assessment on durability and impact resistivity will be verified in the coming research.

Key words: Short discrete, High Strength Concrete (HSC), fineness modulus, Coconut Fibers (CF), Glass Fibers (GF), silica fume, slump test, coarse sand, Fiber Reinforced Cement-based (FRC), Ultrasonic Pulse Velocity (UPV)

INTRODUCTION

ACI Committee had defined High Strength Concrete (HSC) is the concrete that can attain specified compressive strength for design of at least 55 MPa, or more (Caldarone, 2009). As far as concerned, high cementitious content would cause substantially volume changes to the concrete in the earlier age due to the hydration process and hence affecting the strength development (Moon *et al*., 2005). Besides, concrete is brittle due to its low fracture toughness and tensile strain capacity and it is even more pronouncing when silica fume was added for high strength achievement (Koksal *et al.*, 2008; Chandramouli *et al*., 2010a). The brittleness was obviously showed when the concrete cube failed in explosive mode during compression test. Therefore, fiber has come out as a new way to improve the performance of concrete in these matters. Previous had verified that the concrete reinforced hybrid fiber showed enhancement in terms of deflection, crack widths control, splitting tensile strength, flexural strength, ductility performance to avoid sudden failure when ultimate load imposed on the concrete. (Eswari *et al*., 2008; Ravichandran *et al*., 2009).

However, each types of fiber and its composition gives different effects to the performance of FRC. But all of them generally share the same advantages to the concrete which is able to improve the performance of concrete, especially in serviceability aspect. The incorporation of fibers into fresh concrete had significantly altered its rheological behavior that determines the workability of the fresh concrete in respect of stability, mobility and compactability. (ACI Committee 309, 2008). The significant level of reducing effects in workability is greatly depends on two parameter, which are fiber content and aspect ratio. The aspect ratio is the ratio of length to diameter of fiber. The lesser the incorporated fiber content and the lower the aspect ratio of fiber, the minimum the adverse effects would be on the workability of concrete.

Corresponding Author: Mahyuddin Ramli, University Sains Malaysia, Pulau Pinang, Malaysia

Coarser fine aggregates would somehow provide better workability in the rich cementitious mixtures. The larger surface area of finer sand would absorb portions of free water to wet the entire surface of particles but at the same time the finer sand did not contribute to the strength development in a high powdery mixture (Caldarone, 2009).

The present research was intended to study various types of fibers at different content on the mechanical properties of fiber reinforced HSC.

MATERIALS AND METHODS

Type I Portland cement and condensed silica fume were used as binder content for the experiment. The chemical compositions of both cementations compounds were shown in Table 1. River sand with specific gravity 2.51 and fineness modulus 3.98 used as fine aggregate. The particle distribution curves are shown in Fig. 1. Crushed granite as coarse aggregate with specific gravity 2.7 and nominal size 19 mm. Conplast SP 1000, a chloride free super plasticizing admixture based on sulphonated naphthalene polymers which complying BS 5075 used to enhance workability. Coconut fiber, Barchip fiber and Glass fiber with specifications are shown in Table 2-4 respectively.

Table 1: Chemical composition of ordinary Portland cement and Silica fume to manufacturer's detail

	Percentage by weight	
Constituent	Ordinary portland cement	Silica fume
Lime (CaO)	64.64	1.0% (max)
Silica (SiO_2)	21.28	90% (max)
Alumina (Al_2O_3)	5.60	1.2 % (max)
Iron Oxide (Fe_2O_3)	3.36	2.0% (max)
Magnesia (MgO)	2.06	0.6% (max)
Sulphur trioxode (SO_3)	2.14	0.5% (max)
N_2O	0.05	0.8% (max)
Loss of ignition	0.64	6% (max)
Lime saturation factor	0.92	-
C_3S	52.82	-
C_2S	21.45	-
C_3A	9.16	-
C_4AF	10.20	-

Table 2: Specifications of coconut fiber

Item	Unit	Test value
Diameter	mm	0.32
Length	mm	20-30
Tensile strength	mpa	176
Elastic modulus	GPa	22.4
Specific gravity	-	1.13

Experimental program: The mixture composition was kept constant for all mixtures and shown in Table 5. Each type of fiber was added separately to specimens at different volumetric ratio, 0.6, 1.2, 1.8 and 2.4% to the

Table 3: Specifications of Barchip fibers according to Elastro Plastic Concrete Inc

Characteristic	Unit	Material property
Base resin	-	Modified Olefin
Length	mm	24±2
Tensile strength	MPa	640
Surface texture	-	Continuously embossed
No. fibers per kg	Nos	37, 000
Specific gravity		0.95
Young's modulus	GPa	10
Melting point	°C	159-179
Ignition point	°C	>450

Table 4: Specifications of alkaline resistance glass fiber according to Berjaya Bintang Timur (M) Sdn. Bhd

Item	Unit	Standard	Test value
Diameter	μm	15.0±2.3	15.70
Length	mm	24±1.5	24.40
Moisture content	%	≤ 0.2	0.18
Combustible matter content	%	1.9±0.3	1.83
Elastic modulus	GPa	71.7-80.0	72.00
Specific gravity	-	2.6-2.8	2.70
ZrO^2	%	16.8±0.5/0.3	16.57
TiO^2	%	5.5±0.5	5.45

Table 5: Mixture proportions of control mix

Content	Proportion (kg m^{-3})
Cement	435.6
Silica fume	59.4
Water	183.0
Fine aggregate	689.0
Coarse aggregate	1033.0
Superplasticizer	9.9

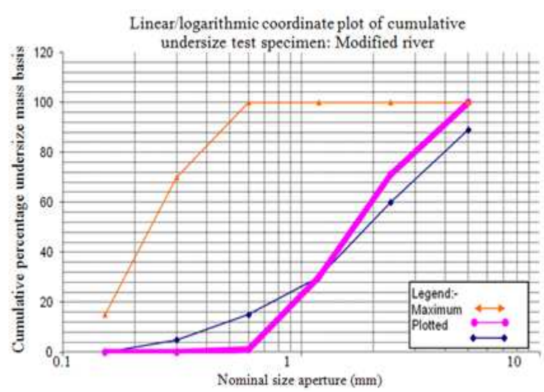

Fig. 1: Particle size distribution of modified sand

volume of binder. A total of thirteen mixtures were produced for this research study, one control mix (control), twelve mixes casted by Coconut Fibers (CF series), Barchip Fibers (BF series) and Glass Fibers (GF series) at volume fractions as described above for each type of fibers. The specimens were tested at the aged of 7 days and 28 days. All of them were demoulded at 24±2 hours after casting and allowed to cure in water at temperature 23±2°C until the age of testing.

Slump test: Every batches of concrete were carried slump test to access the workability of the concrete. The tests were done according to BS EN 12350-2:2009.

Density test: Three cubes with dimension 100×100×100 mm in water saturated condition were used in this test. This test is carried out according to the BS EN 12390-7:2009.

Compressive strength test: The compressive strength test was performed on three cubes with dimension 100×100×100 mm and took the average results. The test was done according to BS EN 12390-3:2009.

Flexural strength test: This test performed on prisms of each type of specimens with dimension 100×100×500 mm, according to BS EN 12390-5:2009, using the Universal Testing Machine. The average of three values was taken to define flexural strength of that particular type of specimen.

Ultrasonic pulse velocity test: This test was done using the Portable Ultrasonic Nondestructive Digital Indicating Tester (PUNDIT), measured in direct method. The PUNDIT consists of two transducers (transmitter and receiver) with frequency of 54 kHz. The transducers were coupled with the concrete surface by grease to ensure perfect contact between them. The ultrasonic pulse would travel through the concrete and the data of time taken and pulse velocity would generate. The average readings of pulse velocity took from three cubes and three prisms was taken as Ultrasonic Pulse Velocity (UPV) value of the specimen.

RESULTS

The average results of all specimens were presented from Fig. 2-6 respectively

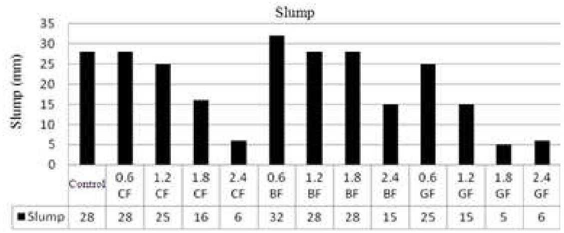

Fig. 2: Slump results for all specimens

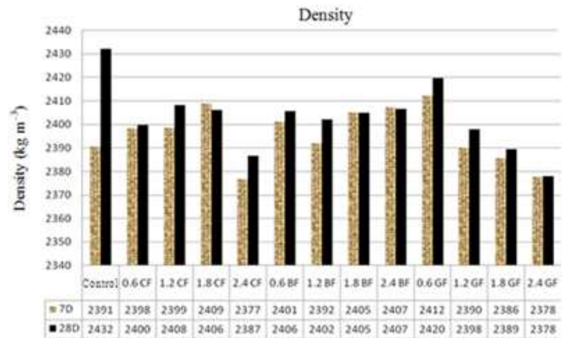

Fig. 3: Average density of all specimens in 7 and 28 days

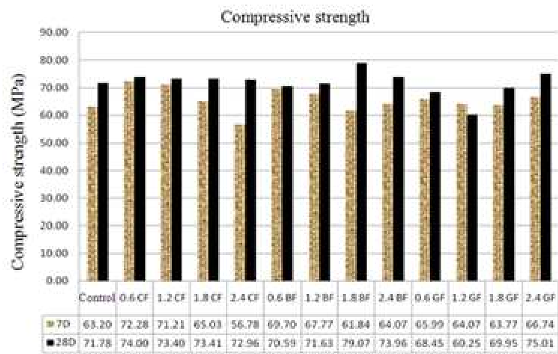

Fig. 4: Compressive strength of all specimens at 7 and 28 days

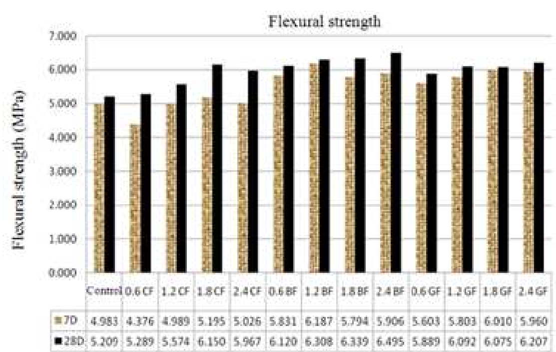

Fig. 5: Average flexural strength for all specimens at 7 and 28 days

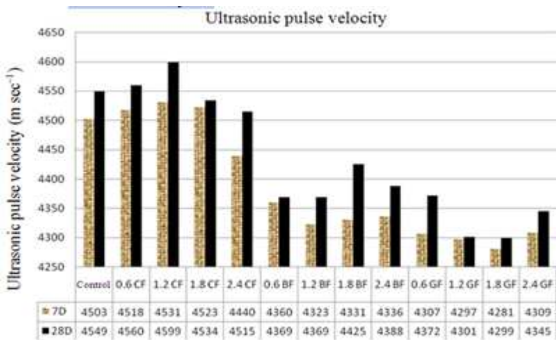

Fig. 6: Average pulse velocity for all specimens at 7 and 28 days

DISCUSSION

Slump test: From Fig. 2, all specimens (CF series, BF series and GF series) shared the same profile of results, which is the increased of fiber content, the slump or the consistency of the freshly mixed concrete would drop. It was due to the friction between the mixture and fibers would increase the cohesiveness of the mixtures and hence made the mixture unworkable. However, it was still depending on other factors like the nature characteristics of the fibers. In CF series, the coconut fibers are relatively high in water absorption compared to Barchip and glass fibers. During the mixing, the coconut fibers partially adsorbed the free water content and hence increased the water demand and reduced the workability of concrete. The glass fibers attained the lowest slump in high volume fractions. The needle like shape of the fibers has high specific surface and noticeably increased the cohesiveness of the mixture compared to the other two types of fiber. Among them, Barchip fibers gave the least effects in reducing workability of the mixture. It was due to the fiber did not absorb the free water content from the mixture. In addition, it has larger diameter so the specific surface contact would be lesser and attribute lesser friction in the mixture even though it has contour surface texture on the surface. Therefore, it can be said that the factors of specific surface, water absorption and surface texture of fibers affected the workability of fresh mixtures in descending order.

Density test: From Fig. 3, the density of majority specimens was increased at the 28 days. The results were shown that the densities of the specimens were in the range of 2377-2412 kg m^{-3} and 2378-2432 kg m^{-3} for 7 days and 28 days respectively. This implied that all of them were categorized as normal weight HSC.

In comparisons of 28 days results, all of the specimens had lower density than control. It was due to the inclusion of fibers into concrete attributed more air voids entrapped in the mixtures. Hence, from the absolute volume point of view, these entrapped airs would reduce the density of concrete. However, the density of concrete would depend on some other judgments like the degree of compactions during the mixing process and specific gravity of incorporated fibers. But since the fibers were incorporated in small amount, the parameter on energy applied in compaction would be more significant.

Compressive strength test: Compressive strength is the most direct measures to the quality of concrete. From Fig. 4, it was clearly shown that 1.8BF (1.8% of Barchip fiber) had the highest compressive strength at 28 days. It was 10.2% higher than the control. However, its 7 day strength was slightly lower than the control, about 2.2%. From the comparison between ratios of compressive strength of 7 days to 28 days, for control, it was 88.0% while for 1.8BF was 78.2%. It was about 10% in reduction. One of the reasons for this could be due to the more complete hydration happened in 1.8BF. Generally, the short discrete random fibers had increased the compressive strength of HSC in both 7 and 28 days. For the case of the specimens reinforced with Coconut Fibers (CF series), 7 days strength was so much improved as compared to control. However, this was true to the low volume fraction of fibers (up to 1.8% of the volume of binder). As the fiber content increase, the compressive strength was dropped considerably. This might be due to the microstructure had impaired by the fibers as they were high in water absorption. It partially absorbed the water needed for hydration purpose. But in 28 days, with continuously water cure, the strength was developed and there were not much differ in volume fraction basis, but still, the 0.6CF was the highest among the CF series. This result was comparable with the study by Ramli and Dawood (2010) on influence of palm fiber to the lightweight concrete crushed brick. They found that 0.8% of volume fraction was the optimum percentage to that type of concrete. (Ramli and Dawood, 2010)

It was also found that the changed in volume fraction of Barchip and glass fiber has large magnitude of influences on the compressive strength of HSC compared to coconut fiber. For glass fiber, the strength slowly decreased from 0.6% and increased again when approaching 2.4%. But, for Barchip fibers, the optimum strength was fall at 1.8% of volume of binder at 28 days even though it obtained the lowest strength at 7 days.

The glass fibers showed negative performance in low volume fraction. At 28 days strength, 1.2GF exhibited the lowest compressive strength among all specimens, which are 16.1% lower than control. However, the increased in GF content increased the strength as well. 2.4 GF obtained the highest strength among GF series. Despite of the reinforcing effects, the increased in strength might also due to more compacting of the microstructure of the concrete which already verified by Chandramouli *et al*. (2010b) that glass fibre concrete has lower permeability for all grades of concrete. (Chandramouli *et al.*, 2010a)

Among 3 types of fibers, Barchip fiber is the best quality among them. It has very high tensile strength (640 MPa) and contour surface which is specially engineered to create strong bonding with concrete matrices. The bonding between fibers with the concrete matrices had resulted better load transfers within the micro structures of the concrete under axial loadings. Furthermore, fibers were also reduced the cracks formation occurred in microstructures of concrete under axial loading and resisted cracks propagations. However, the degree of influences was depends on the volume fractions (Topcu and Canbaz, 2007; Brandt, 2008). This explained why it showed the highest strength among other fibers at the optimum content

Flexural strength test: From Fig. 5, the flexural strength of HSC was increased regardless of types of fibers. The highest flexural strength from respective series was 1.8CF, 2.4BF and 2.4GF at 28 days. Each of them was higher than control by 18.1, 24.7 and 19.2% respectively. Among them, Barchip Fibers (BF series) showed the highest enhancement in this way. In comparisons with 7 days results, 1.2 BF obtained the highest flexural strength which is 24.2% higher than control. Generally, as supported by literature reviews and experimental results, fibers would increase the flexural strength or the bending capacity of the concrete. This is very important especially for HSC with silica fume which is brittle in nature. There was a mechanisms could be explained on how fibers increased the flexural strength of the specimens. Initially was the cracking happened at the matrix by imposed loading and then the fiber would be ruptured. If the fibers are tough or high in tensile strength, the interfacial zone between the fibers and concrete matrix played an important role as the debonding process occurred before the fibers were ruptured. A highly effective reinforcing effects would attained by good bonding between fiber/matrix interfacial zone and consequently slowing down the crack propagation process. Eventually, the fiber would pull-out by the loadings and it was the time when the specimens failed in bending (Reis, 2006). During the pull-out process, mechanical effects of the fibre also play an important role in further enhancing the peak load (Abu-Lebdeh *et al*., 2010). Compared to the control, the mechanism would be cracking at the matrix and then straight away to the failure of matrix. From this, it could be explained that why Barchip fibers is the best among them in enhancing bending capacity of HSC. It was tough, with high tensile strength and embossed treatment to the surface so as to have good bonding with concrete matrix was greatly slowed down the cracks propagations process and failed when the fibers were pulled out. But, the pulled out process was only occurred to the Barchip fiber, compared to coconut and glass fiber.

The coconut fibers performed not so well at the 7 days compared to control and other types of fiber. In low volume fraction (0.6CF), it was even to have deleterious effects on the flexural strength of concrete. However, with the adequate curing, the flexural strength was well developed at the 28 days. The optimum fiber content was 1.8% for CF series which is 16.3% higher than control. The CF series attained lower flexural strength compared to BF series might be due to the coconut fibers has lower tensile strength (120-200 MPa) and lower elastic modulus (19-26 GPa), which means that it has poorer quality. After the specimens failed, it was observed the fibers had ruptured prior to the failure of specimens in bending. By the way, the flexural strength was still comparable to that of Barchip fibers, which implied that the reinforcing effects were still there.

For Glass Fibers (GF series), a more consistence results were obtained. The flexural strength was increased in the range of 12.4-19.6 and 13.1-19.2% for 7 days and 28 days respectively compared to control. These were higher than CF series specimens. From the observations with the aid of magnifying lens, the glass fibers were also ruptured prior to the failure in bending. However, the needle like shape in small diameter (15 ± 2.3 μm) had increased the specific surface to optimize the reinforced effects even though the surface of fibers was relatively. Noted that the glass fibers were bundled together with hundreds of filaments or strands in length 24 ± 1.5 mm in packaging size, but after mixed into concrete, the strands were dispersed. In additions, the elastic modulus of glass fibers (71.7-80.0 GPa) was also higher than coconut fibers. They were able to sustain higher uniaxial stress to a unit of strain.

Ultrasonic pulse velocity test: Figure 6 was displayed that the Ultrasonic Pulse Velocity (UPV) of specimens were fall in the range of 4.28-4.53 km sec^{-1} and 4.30-4.60 km sec^{-1} for 7 and 28 days respectively. Therefore, they were generally categorized as sound concrete or good quality concrete which implied that there was no honey combs existed in the concrete.

Among all specimens, 1.2CF obtained the highest UPV for both 7 days and 28 days respectively. It was higher than control about 0.6 and 1.1% for both ages. The lowest UPV was attained by 1.8 GF at both 7 and 28 days. It was lower than control about 4.9 and 5.5% for both ages. For all specimens in BF series and GF series, they attained lower UPV value compared to control.

From this test, it was also found that the UPV values were increased over the time. It could be due to the denser structures in the specimens formed by the longer hydration period in the curing tank. Comparing between the UPV values obtained by BF series and GF series, the BF series has averagely higher UPV values than GF series at both 7 and 28 days. The average value of UPV for BF series at 7 and 28 days was 4.34 km sec^{-1} and 4.39 km sec^{-1} respectively while for BF series was 4.30 km sec^{-1} and 4.33 km sec^{-1} respectively. It signified that the BF series specimens might have more compacted microstructures than GF series specimens as the workability of BF series were generally higher.

CONCLUSION

From this study, we can make several conclusions as follow:

- The workability of fiber reinforced HSC was decreased as the volume fraction of incorporated fibers increased. Among three types of fibers, Barchip fibers have the less negative effects on workability while glass fibers in high volume fractions have the worst effects in reducing the consistency of concrete
- Density of concrete was increased over the age. Introduction of fibers into HSC was slightly reduced the density on concrete. Glass fiber was affecting the density in highest magnitude. However, the fibrous HSC was still fall in the category of normal weight concrete
- Short discrete randomly distribute fibers had the ability to increased both compressive strength and flexural strength of HSC. Barchip fibers showed the best in both ways among them.
- The coconut fiber content was inversely proportional to the compressive strength of HSC

All of the specimens have UPV values more than 4.280 km sec^{-1}, which implied that the concrete specimens are in good quality. The introduction of fibers into HSC has reduced the UPV values, except for low volume fraction (0.6 and 1.2%) of coconut fibers.

ACKNOWLEDGEMENT

The authors would like to thank to Universiti Sains Malaysia providing fellowship and grant USM-RU-PGRS Grant No. 1001/PPBGN/843058 which enable the research to progress smoothly.

REFERENCES

Ravichandran, A., K. Suguna and P.N. Ragunath, 2009. Strength modeling of high-strength concrete with hybrid fibre reinforcement. Am. J. Applied Sci., 6: 219-223. DOI: 10.3844/ajassp.2009.219.223

Abu-Lebdeh, T., S. Hamoush and B. Zornig, 2010. Rate effect on pullout behavior of steel fibers embedded in very-high strength concrete. Am. J. Engineer. Applied Sci., 3: 454-463. DOI: 10.3844/ajeassp.2010.454.463

ACI Committee 309, 2008. Behaviour of fresh concrete during vibration (ACI 309.1R). http://www.concrete.org/pubs/newpubs/309.1R-08web.pdf

Brandt, A.M., 2008. Fiber Reinforced Cement-based (FRC) composites after over 40 years of development in building and civil engineering. Comp. Struct., 86: 3-9. DOI: 10.1016/j.compstruct.2008.03.006

Caldarone, M.A., 2009. High-Strength Concrete a Practical Guide. 1st Edn., Taylor and Francis, US and Canada. pp: 1-119. ISBN: 0-203-96249-4

Chandramouli, K., P.S. Rao, N. Pannirselvam, T.S. Sekhar and P. Sravana, 2010a. Chloride penetration resistance studies on concrete modified with alkali resistant glass fibers. Am. J. Applied Sci., 7: 371-375. ISSN: 1546-9239

Chandramouli, K., P.S. Rao, N. Pannirselvam, T.S. Sekhar and P. Sravana, 2010b. Chloride penetration resistance studies on concretes modified with alkali resistant glass fibers. Am. J. Applied Sci., 7: 371-375. DOI: 10.3844/ajassp.2010.371.375

Eswari, S., P.N. Raghunath and K. Suguna, 2008. Ductility performance of hybrid fibre reinforced concrete. Am. J. Applied Sci., 5: 1257-1262. DOI: 10.3844/ajassp.2008.1257.1262

Koksal, F., F. Altun, I. Yigit and Y. Sahin, 2008. Combined effect of silica fume and steel fiber on the mechanical properties of high strength concretes. Constr. Buil. Mater., 22: 1874-1880. DOI: 10.1016/j.conbuildmat.2007.04.017

Moon, J.H., F. Rajabipour, B. Pease and J. Weiss, 2005. Autogenous Shrinkage, Residual Stressand Cracking in Cementitious Composites: The Influence of Internal and External Restraint. In: Proceedings of the 4th International Research Seminar, Gaithersburg, Persson, B., D. Bentz and L.O. Nilsson (Eds.). Lund Institute of Technology, Sweden, Maryland, USA, pp: 1-20. ISBN: 91-631-7102-3

Ramli, M. and E.T. Dawood, 2010. Effects of palm fiber on the mechanical properties of lightweight concrete crushed brick. Am. J. Eng. Applied Sci., 3: 489-493. ISSN: 1941-7020

Reis, J.M., 2006. Fracture and flexural characterization of natural fiber-reinforced polymer concrete. Constr. Buil. Mater., 20: 673-678. DOI: 10.1016/j.conbuildmat.2005.02.008

Topcu, I.B. and M. Canbaz, 2007. Effect of different fibers on the mechanical properties of concrete containing fly. Ash. Constr. Buil. Mater., 21: 1486-1491. DOI: 10.1016/j.conbuildmat.2006.06.026