ANNALS of Faculty Engineering Hunedoara – INTERNATIONAL JOURNAL OF ENGINEERING
Tome XIX [2021] | Fascicule 2 [May]

[1.]Christopher Ajiboye FAPOHUNDA, [2.]Abiodun J. KILANI

SOME STRUCTURAL PERFORMANCE EVALUATION OF CONCRETE REINFORCED WITH EMPTY PALM OIL FRUIT BRUNCH FIBRES (OPE-FBF)

[1,2.]Department of Civil Engineering, Federal University, Oye-Ekiti, NIGERIA

Abstract: Innovative application of agricultural waste will promote sustainable production of structural concrete and serve as catalyst for economic development. This paper presents the results of investigation conducted to assess the structural implications of the use of empty palm oil fruit brunch fibre (OPE-FBF) in the production of structural concrete. The properties of mortar and concrete with OPE-FBF investigated were: consistency, setting times, workability, density, compressive sand tensile strength. The results showed that: (i) inclusion of oil palm empty fruit bunch fiber (OPE-FBF) in concrete reduced the setting times of the concrete, thus has a retarding effect on the concrete, (ii) inclusion of oil palm empty fruit bunch fiber (OPE-FBF) in concrete reduced the workability of the concrete samples, (iii) inclusion of oil palm empty fruit bunch fiber (OPE-FBF) in concrete resulted in concrete with densities ranges for normal weight structural applications and (iv) inclusion of oil palm empty fruit bunch fiber (OPE-FBF) in concrete increase the compressive strength in relation to the control up to 0.60% addition. Thus, using OPE-FBF up to 0.6% improves the strength of concrete, but its workability can be improved with the use of superplasticizer.

Keywords: Compressive strength, Consistency, Oil palm empty fruit brunch, Setting Times, Tensile Strength, Workability

1. INTRODUCTION

It is a well-established fact that concrete is one of the most widely used construction material in the world today (REF). Abundance of many civil infrastructure works, especially building of all types and for diverse purposes, constructed in concrete, attest to this. The fact that it has good compressive strength, durability, fire resistance and can be cast to fit any structural shape are some of the reasons for its worldwide use for construction. But as strong as the concrete is, there is a major flaw. The tensile strength of concrete is much lower than its compressive strength, making it brittle and susceptible to crack development under low tensile stress (Cho et al., 2019). Although, reinforcement is used to mitigate the low tensile stress, the problem of crack initiation and propagation is not solved. This has led to the introduction of fibres into reinforced concrete in the construction industries. The use of fiber for construction purposes is as old as antiquity. Most construction works in ancient Egyptian civilization, as documented by Moses (about 2000BC), in the translation done by Douay (1582) and Nelson (1990) contained fibers, in the form of straw. It is however obvious that the use of straw in the ancient times was simply for construction purposes, and not for special application of crack-controlling measures. Nowadays, many materials have been used as fibers. Kaniraj and Fung (2018) classified into synthetic, metallic and natural fibres as shown in Table 1 (the number inside the parentheses show the number of investigations in which that types of fibre has been used). Apart from natural fibers, others type of fibre are very expensive and resulted in un-economic construction, thereby limiting there wide spread use. In addition to those listed in Table 1, other materials used as natural fibres are fibers of jute, ramie, flax, kenaf and hemp are obtained from the stem whereas sisal, banana and pineapple are obtained from the leaf and cotton and kapok from the seed. These fibers, in the unprocessed or processed form, have been used to reinforce cement-based products in various applications around the world.

Table 1: Types of Fibers used in Research Studies (Kaniraj and Fung, 2018)

Synthetic	Metallic	Natural
Polyamide (nylon) (3)	Aluminum (foil, rod) (3)	Bhabar (1)
Polyester (6)	Copper (wire) (3)	Coir (4)
Polyethylene (fibre, mesh, strip) (2)	Galvanized steel (1)	Human hair (1)
Polypropylene (Crimpled fibre fibrillated fibre, monofilament fibre, mesh, pulp, tape) (30)	Steel (rod wire) (5)	Oil palm empty fruit bunch (1)
Polyvinyl alcohol (1)	Stainless Steel (1)	Palmyra (3)
Polyvinyl chloride (1)		Reed (3)
Polyethylene terephthalate (1)		Rubber (1), Wheat Straw (1)

Figure 1: Oil Palm Empty Fruit Brunch as Waste

The prevalence of oil palm empty fruit brunch, produced as waste in oil milling industry (Figure 1), is however attracting the attention of researchers as a sustainable source of fibre in the production of structural concrete.

Ramli and Dawood (2010) studied the effect of OPE-FBF on the mechanical properties of lightweight concrete. Results from their investigation showed that: (i) the use of this fiber slightly increases the density of lightweight concrete, (ii) use of up to 0.8% of palm fiber increases the compressive strength and flexural strength by about 13.4 and 16.1% respectively. In their own works, Ismail and Yacoob (2011) investigated the properties of Laterite Brick Reinforced with Oil Palm Empty Fruit Bunch Fibres. Findings from their work showed decrease in the density of laterite bricks increase in the OPEFB fibre content of the brick and improved the compressive strength of the bricks at 3% fibre content. The above review shows that little work has been done on the structural implications of inclusion of oil palm empty fruit bunch fibres (OPE-FBA) in concrete. Thus, the aim of this paper is to evaluate the performance concrete containing varying percentages of untreated oil palm empty fruit bunch fiber (OPE-FBF) so as to appraise their potential and feasibility for structural and non-structural applications. Some of the objectives set to achieve this are the determination of the effects of inclusion of OPE-FBF on some structural properties of paste and concrete such as: consistency, setting times, workability, density, compressive strength and the tensile strength.

2. MATERIALS AND METHOD

— Materials and Mix Proportions

The materials that were used for this study are: cement, fine aggregate, coarse aggregate, empty palm oil fruit brunch fibre (OPE-FBF), and potable water. The cement used was Portland limestone cement of 42.5 grade satisfying the requirement of requirements NIS 444 (2014) and BS EN 197-1 (2000). The fine aggregate used was river sand which was obtained from a River FUOYE flowing adjacent to the Ikole Campus of the Federal University, Oye-Ekiti, Nigeria. In order to meet the requirement of BS EN 12620:2002+A1 (2008), the sand was dried and sieved. The portion passing through BS sieve no 4 (4.75 mm) but retained on BS sieve no 200 (75 um) was collected, bagged and stored in cool place. The coarse aggregate used for this investigation was obtained from an active quarry site in Ikole-Ekiti, Nigeria. The sizes of the coarse aggregate ranged from 4.75mm to a maximum of 20 mm according as per the recommendation of BS 8110 (1997) in relation to for structural concrete. In order to obtain the empty palm oil fruit brunch fibre (OPE-FBF), empty palm oil fruit brunches were collected from palm oil industries in Ikole-Ekiti, Nigeria. The brunches were soaked in water so easy extraction of the fibre. The fibers were then sun-dried and cut into 20 mm length. The extracted fibre is shown in Figure 2. Potable water, that meets the requirement of ASTM 1602 (2012) was used for this study.

Figure 2: Oil palm empty fruit bunch fibres (OPE-FBF): (a) the Oil palm empty fruit bunch, (b) the fibre before extraction and (c) the fibres after extraction

— Mix Proportion, Design and Concreting

In order to model as much as possible, the common practice in Nigeria, a mix proportion of 1: 2: 4 was chosen with the water cement ratios of 0.40, 0.50 and 0.60. The OPE-FBF was added up to 1.20% by weight of cement at interval of 0.20%, and randomly mixed with the cement. This range was chosen based on findings from literature (Kaniraj and Fung, 2018) in relation to natural fibres usage in concrete. The mix proportion in Table 1 was developed on the basis of this. Concrete ingredients were batched by weight, thoroughly mixed by following the sequence suggested by Gambhir (2013). The concrete was cast into 150 x 150 x 150 mm cube moulds for compressive test specimens and 150 x 300 mm cylinder moulds for splitting tensile test specimens.

Table 1: Mix Proportion for the Investigation

% Fibre in the Mix	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Fibre (kg/m^3)	Water (kg/m^3)
0%	343	686	1372	0.00	172
0.2	343	686	1372	0.69	172
0.4	343	686	1372	1.37	172
0.6	343	686	1372	2.06	172
0.8	343	686	1372	2.74	172
1.0	343	686	1372	3.43	172
1.2	343	686	1372	4.12	172

The cast concrete was given adequate compaction. The specimens were then left in the moulds for 24 hours, de-moulded, and then placed in curing tank for moist-curing process until the day of testing. The testing days were 7, 14, 28, 60 and 90 days. The specimens without OPE-FBF served as the control.

— Experimental Investigations

≡ Characterization of Materials

Some preliminary investigation was carried out to characterized the materials. These are the properties of aggregates. The physical and elemental chemical properties of OPE-FBF were also carried out

≡ Main Investigation

The main structural investigation carried out were described as follows

≡ Consistency Test

Consistency test was performed on mortar specimens containing OPE-FBF in accordance with BS EN 196-3 (2005) by using the Vicat probe and the Vicat needle apparatus. This is necessary so that quantity of water required to achieve a paste of normal consistence for the samples can be ascertained. To the paste was added OPE-FBF progressively 0. 00%, 0.20%, 0.40%, 0.60%, 0.80%, 1.00% and 1.20% of cement. The water demand for zero replacement of cement with OPE-FBF serves as the control.

≡ Setting Times Test

The water required to achieve the standard consistency of cement paste at zero percent OPE-FBF, as determined from the consistency test in accordance to BS EN 196-3 (2005), was used to evaluate the effect of OPE-FBF on the setting times (initial and final) of cement paste. The setting times – both initial and final – were then determined at the cement replacement value with OPE-FBF up to 15% at the interval of 5%.

≡ Workability Test

With the purpose of determining the ease and homogeneity with which freshly mixed concrete with OPE-FBF can be mixed, placed, consolidated and finished without bleeding and segregation, workability test was carried out on the concrete specimens containing OPE-FBF. The test was performed through the slump test in accordance with the provisions of BS EN 12350: Part 2 (2000).

≡ Density and Compressive Strength Tests

The density and the compressive strength of concrete specimens containing OPE-FBF were assessed using 150 x 150 x 150 mm cube specimens. The determinations of densities were done in line with the provisions of BS 12350: Part 6 (2000). Similarly, the provisions of BS EN 12390-3 (2009 governed the determination of the compressive strengths. A 2000KN WAW-2000B computerized electrohydraulic servo universal testing machine with accuracy of ± 1% of test force, was the equipment used for the determination of the compressive strength. At each curing age, three specimens were tested, and the average was used to evaluate the mean strength. However, before the testing of the specimens, the concrete cube specimens were the weighed and the values obtained were subsequently used to calculate the density of the concrete cube specimens.

≡ Tension Test

The splitting tensile strength test was used to determine the strength of the concrete specimens containing OPE-FBF, in tension. The splitting tensile strength test was carried out by using 150 x 300 mm cylinder moulds, in accordance to the provision of BS 12390: Part 6 (2009). The equipment used to carry out this test was 2000KN WAW-2000B computerized electrohydraulic servo universal testing machine with accuracy of ± 1% of test force. The splitting tensile strength (Ts) was later obtained using equation 1.

$$T_s = \frac{2P}{\pi l d} \tag{1}$$

where: Ts is the splitting tensile strength (N/mm^2), P is the maximum applied load (in Newtons) by the testing machine, l is the length of the specimen (mm), and d is the diameter of the specimen (mm).

3. RESULTS AND DISCUSSION

— Characterization of Materials

The results conducted to characterize the materials are presented in Table 2 and 3.

From Table 2, it can be seen that the specific gravities of fine aggregate and coarse aggregate are 2.63 and 2.67 respectively. The average specific gravity of majority of natural aggregate is known to lie between 2.5 and 2.8 (Gambhir, 2013), Thus, both the fine aggregate and coarse aggregate used in this investigation can be considered as natural aggregate. Also, the bulk density, water absorption and the moisture content of both the fine aggregate and coarse aggregate fell between the ranges used in normal concrete (ACI, 1999). These values are 1280 to 1920 kg/m³ for density, 0 to 8% for water absorption, and 0 – 2% as moisture content for fine aggregate and 0 - 10% as moisture content for coarse aggregate. The general conclusion from Table 2 is that both the fine aggregate and coarse aggregate materials are good for concrete production. Also, presented in Table 3 are some physical, elemental chemical properties of OPE-FBF.

Table 2: Some Physical Properties of the Aggregates

	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.63	2.67
Bulk Density (kg/m^3)	1666.67	1641.67
Water Absorption (%)	2.00	2.00
Moisture Content (%)	0.00	0.00
Coefficient of curvature (Cc)	0.88	0.98
Coefficient of uniformity (Cu)	3.00	2.43

Table 3: Some Physical and Chemical Properties of the OPE-FBF

Properties	Value
Colour	Brown
Length (mm)	20
Diameter (mm)	0.25 – 0.50
Aspect Ratio	53
Density (g/cm^3)	1.07
Water Absorption (%)	35.78
Moisture Content (%)	0.014
Hemi-cellulose (%)	12.60
Cellulose (%)	38.50
Lignin (%)	19.00
Extraction (%)	0.45
Ashes (%)	5.25
Pentosan (%)	21.50
Tensile Strength (GPa	172.50
Young Modulus (GPa)	5.21

— Consistency and Setting Times

The results of the consistency and the setting times of paste with OPE-FBF are presented in Table 4.

It can be seen from the Table that water requirement for standard consistence changed marginally with inclusion of OPE-FBF at the percentages considered. However, inclusion of OPE-FBF in the cement paste reduced both the initial and setting times significantly. The reduced initial setting times are particularly is very instructive that OPE-FBF as an accelerator when used in concrete. That is, the concrete will harden quickly. The implication is that, concrete containing OPE-FBF may not be used if the concrete will be carried over a long distance.

Table 4: Consistency and Setting Times of Samples with OPE-FBF

% Fibre in the Mix	Consistency	Initial Setting Times (minutes)	Final Setting Times (Minutes)
0%	33	175	340
0.2	34	37	278
0.4	34	30	232
0.6	34	15	170
0.8	35	10	170
1.0	35	10	150
1.2	35	5	150

— Workability

The results of workability test of concrete with OPE-FBF is presented in Table 5.

It is obvious from the Table that the inclusion of OPE-FBF at the percentage of addition considered resulted in concrete with very low workability. The fact that there was no slump loss when OPE-FBF was included is in agreement with the results of setting times in Table 4. The samples however displayed true slump suggesting that cohesive integrity of the material was not disrupted despite the very low workability. The structural implication of this behavior is that the use of superplasticizer should be considered to make the concrete workable when OPE-FBA is being considered for use.

Table 5: Workability of Concrete Samples with OPE-FBF

% Fibre in the Mix	Slump Loss	Type of Slump	Workability
0%	20	TRUE	Very Low
0.2	0	TRUE	Very Low
0.4	0	TRUE	Very Low
0.6	0	TRUE	Very Low
0.8	0	TRUE	Very Low
1.0	0	TRUE	Very Low
1.2	0	TRUE	Very Low

— Density

The developed densities of concrete specimens with OPE-FBF at the levels of addition considered and at the curing ages are shown in Table 6. The density development characteristics of concrete, especially when new materials are incorporated into it, determines the manner of its application in practical terms. This is because three categories of densities exist in structural concrete. According to (ACI 213 (2003) and Falade et al., 2011)), they are:

Table 6: The developed densities of Concrete specimens with OPE-FBF

% fibre in the Mix	Density (kg/m³)/Curing Age (days)				
	7	14	28	60	90
0	2413.8	2334.80	2388.1	2492.8	2421.7
0.2	2425.7	2366.42	2435.6	2447.4	2346.7
0.4	2500.7	2443.46	2382.2	2409.9	2354.6
0.6	2405.9	2395.80	2449.4	2330.9	2445.4
0.8	2402.0	2348.64	2356.5	2362.5	2427.7
1.0	2455.3	2382.22	2419.4	2392.1	2400.0
1.2	2366.4	2380.25	2354.5	2330.9	2135.1

- lightweight concrete with densities less than 2200 kg/m³,
- normal weight concrete with densities ranging between 2200 – 2550 kg/m³ and
- heavy weight concrete have densities greater than 2550 kg/m³. From the results of densities of the concrete specimens presented in Table 6, the densities ranges from 2135.10 – 2500.70 kg/m³. This is the range of densities for normal weight application. The implication is that concrete containing OPE-FBF can be used for normal structural concrete applications.

— Compressive Strength

The strength development characteristics of concrete specimens containing OPE-FBF is presented in Figure 3. From the figure, the following patterns can be observed.

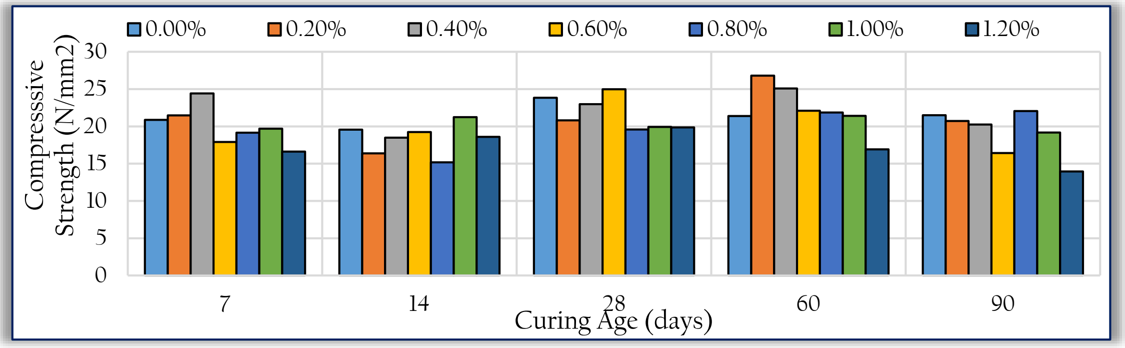


Figure 3: Compressive Strength development of Concrete samples with OPE-FBF

Firstly, compressive strength increased with curing ages for all the samples. Secondly, the compressive strength increases with OPE-FBF content and higher than the samples without OPE-FBF until 0.60% and then began to decrease. Most importantly, the compressive strength developed by the specimens with OPE-FBF at 28-day curing were higher than the specimens without OPE-FBF. Since 28-day compressive strength is universally taken to be an index of good quality concrete (Shetty, 2009 and Neville, 2011), and the only property taken into consideration concrete construction, addition of OPE-FBF in concrete up to 0.60% by weight of cement improve the quality of the concrete. Though, the compressive strength decreased afterward for all the samples. This is due to the drying out of water in the curing tank for the remaining times of the testing period, due to unavoidable reasons. So, hydration stopped during this time. That was the reason why compressive strengths decreased afterwards for all the specimens.

— Tensile Strength

Table 6: The developed Tensile Strength of Concrete specimens with OPE-FBF

% fibre in the Mix	Tensile Strength (N/mm²)/Curing Age (days)				
	7	14	28	60	90
0	0.99	0.86	1.03	0.83	0.87
0.2	1.06	0.75	1.09	0.95	0.86
0.4	1.02	0.85	1.05	0.95	0.83
0.6	0.77	1.02	0.93	0.99	0.77
0.8	0.82	0.77	0.89	0.78	1.00
1.0	0.87	0.93	0.98	0.95	0.78
1.2	0.83	0.87	0.87	0.65	0.68

The developed tensile strengths of specimens with OPE-FBF, assessed through the splitting tensile strength test are shown in Table 6. The splitting tensile strength of all the specimens were low. The reason could be due the bond stress between the fibre and the matrix.

According to Shetty (2009), a good bond is essential for improving the tensile strength of the fibre-based composite. The apparent poor bond may be due to the fact the OPE-FBF used in this investigation were used raw, without any chemical pre-treatment. This might have accounted for the low in tensile properties (Table3). Thus, for improved tensile performance, coating of the fibres with sodium hydroxide or acetone may be given consideration. Although, in reinforced concrete construction, only the compressive strength is taken into consideration, obtaining an improved tensile strength will results in overall integrity of the structure.

4. CONCLUSIONS AND RECOMMENDATIONS

From the analysis of the results of this investigation, the followings can be concluded.

1. Inclusion of oil palm empty fruit bunch fiber (OPE-FBF) in concrete reduced the setting times of the concrete, thus has a retarding effect on the concrete

2. Inclusion of oil palm empty fruit bunch fiber (OPE-FBF) in concrete reduced the workability of the concrete samples.
3. All the concrete specimens containing oil palm empty fruit bunch fiber (OPE-FBF) up to 0.60% developed higher compressive strength than specimens with OPE-FBF

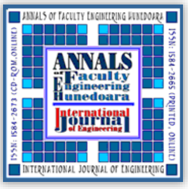
Although, the knowledge of the use of fibers, hitherto employed as construction materials has been lost, the findings from this investigation can be considered as the beginning of the recovery process. Other properties of concrete with OPE-FBF still need to be investigated in order to capture the whole structural response of the use of OPE-FBF in concrete. These properties include: shear and bending performance, durability properties in all environment, amongst many others. These are thus recommended for investigation.

Acknowledgement

The authors graciously acknowledge the technical support of the staff of the Concrete Laboratory, Civil Engineering Department, Federal University Oye-Ekiti, for their assistance, during the period that the investigation was carried out.

References

[1] ACI. "Aggregates for Concrete". ACI Education Bulletin – E1-99, American Concrete Institute, American Concrete Institute, Farmington Hills, Michigan, 1999.
[2] ACI. "Building code requirements for structural concrete (ACI 318M-08) and commentary". American Concrete Institute, Farmington Hills, Michigan, 2008.
[3] ACI Committee 213. "Guide for Structural Lightweight Aggregate Concrete ACI 213R-03)". American Concrete Institute, Farmington Hills, Michigan, 2003.
[4] ASTM C33. "Concrete and Aggregates - ASTM Standards, Concrete and Aggregates". American Society for Testing and Materials, Philadelphia, 1997.
[5] ASTM C 1585. "Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concrete". American Standard for Testing Materials, Philadelphia, 2004.
[6] ASTM C330. "Standard specification for lightweight aggregates for structural Concrete". American Society for Testing and Materials International, Philadelphia, 2009
[7] BS 12. "Specification for Portland Cement". British Standard Institution, London, 1996.
[8] BS 8110. "Structural use of concrete". British Standard Institution, London, 1997.
[9] BS EN 12350 Part 2. "Method for Determination of slump". British Standard Institution, London, 2000.
[10] BS EN 12350 Part 6. "Method for Determination of Density". British Standards Institution, London, 2000.
[11] BS EN 197-1 (2000). Cement, Composition, Specification and Conformity Criteria for Common Cements. British Standard Institution, London.
[12] BS EN 196-3 (2005). Determination of Setting Times and Soundness. British Standard Institution, London.
[13] BS EN 12620:2002+A1. "Specification for Aggregates from Natural Sources for Concrete". British Standards Institution, London, 2008.
[14] BS EN 12390-3. "Testing Hardened Concrete: Compressive Strength of Test Specimens". British Standard Institution, London, 2009.
[15] Cho, C., Cheong, S., Moon, H., Kim, K and Lee, K. "Experimental Study on Seismic Capacity of Reinforced Concrete Composite Columns Based on a High-ductile Fiber Cementitious Composite". International Journal of Concrete Structures and Materials, 13:16., 2019.
[16] Douay-Rheims (1582). Moses – Exodus, 5: 7.
[17] Falade, F., Ikponmwosa, E., and Arogundade, A. "Investigations of Some Structural Properties of Foamed Aerated Concrete". Journal of Engineering Research, 16(1): 67 – 81, 2011.
[18] Ismail, S. and Yacoob, Z. "Properties of Laterite Brick Reinforced with Oil Palm Empty Fruit Bunch Fibres". Pertanika J. Sci. & Technol. 19 (1): 33 – 43 (2011)
[19] Kaniraj, S. R. and Fung, Y. C. "Influence of Discrete Fibers and Mesh Elements on the Behaviour of Lime Stabilized Soil". Pertanika J. Sci. & Technol. 26 (4): 1547 – 1570, 2018.
[20] Nelson (1990). Moses – Exodus, 5: 7. New International Version of the Holy Scriptures.
[21] Neville, A. M. "Properties of Concrete" 5th Edition, Pearson Education, London, 2011.
[22] NIS 444-1. "Cement – Part I: Composition and Conformity Criteria for Common Cements". Standard Organization of Nigeria, Abuja Nigeria, 2014.
[23] Ramli, M and Dawood, E. "Effects of Palm Fiber on the Mechanical Properties of Lightweight Concrete Crushed Brick". American J. of Engineering and Applied Sciences 3 (2): 489-493, 2010
[24] Shetty, M. S. "Concrete Technology". Multi-color Edition, S. Chand and Company Ltd, New Delhi, 2009



ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

5, Revolutiei, 331128, Hunedoara, ROMANIA
http://annals.fih.upt.ro