Strength Characteristics of Concrete with Plastic Granules as Partial Replacement for Sand

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ABSTRACT

The rising cost of concrete materials, as well increase in waste plastic junks, at the backyards or around buildings in cities in Nigeria necessitate research into the possibility of a more productive use of plastic waste in concrete production or for other purposes. This work presents the results of experimental investigation on the effect of partial replacement of fine aggregate with plastic granules on the workability and compaction characteristics of concrete. Granulated plastic, obtained from waste plastic water tank, was used as partial replacement of sand by 5%, 10%, 15% and 20%. Zero percent replacement was adopted as reference concrete mixture. Nominal mix ratio of 1:2:4 was used for this study and mix compositions were calculated by absolute volume method. Test result show that partial replacement of sand with granulated plastic led to increase in workability and slump of fresh concrete. Increase in partial replacement of sand with granulated waste plastic from 5 – 15% led to increase in compacting factor of fresh concrete. Above this replacement, the compacting factor reduced. Water absorption of fresh concrete also decreased after 10% replacement. The average compressive strength developed by concrete cubes with 0%, 5%, 10%, 15%, and 20% replacement of sand with plastic granules after twenty-eight days curing is 27.50 N/mm^2, 24.70 N/mm^2, 26.22 N/mm^2, 19.19 N/mm^2 and 21.82 N/mm^2 respectively. The higher the percent replacement of sand with plastic granules, the lower the strength. Concrete with partial replacement of sand with granulated plastic has average dry density of 1752 kg/m^3, which is within the range stipulated for structural lightweight concrete (1440 – 1840 kg/m3). Therefore, concrete with granulated plastic may be used as partial replacement for sand where lightweight or low density concrete is required.

Keywords: ***Compressive strength; Concrete; Fine aggregate; Partial replacement; Plastic waste; Sand; Workability.***

1.0 INTRODUCTION

Increase in construction activities as well as industrialisation is fast making sourcing good materials for concrete production a herculean task. The recent global increase in the construction of houses, and other infrastructures has led to high consumption of natural sand and other construction materials. The availability and cost of concrete materials greatly affect the cost of concrete production. In order to meet up with the cost and material demand, environmentally applicable skills and effective cost with the available locally sourced materials are fast being explored and adopted (McGinley and Choo, 1990; Shetty, 2004; Salawu, 2007).

Workability is the amount of useful internal work necessary to produce full compaction. The workability of concrete describes the ease of mixing, placing, spreading, compacting and finishing of the concrete in its fresh state. Workability describes the useful energy required for full compaction of fresh concrete. Concrete is said to be workable, if it has the mixing texture, spreading (flowing ability), stability as well as finishing ability. The main factor which affect the workability of concrete is water content (Neville, 2003; Neville and Brook, 1987).

Olawuyi (2010) opined that the optimum workability of fresh concrete varies from situation to situation. Edward (2008) through series of investigations concluded that, the shape, size, grading and surface texture of aggregate, coarse/fine aggregate ratio as well aggregate/cement ratio affect the workability of concrete. The slump of concrete describes the consistency of the mix of such concrete (Dugal, 2010). Industrial wastes can be exploited in concrete production as partial replacement of cement, sand or as an additive component. Edward (2008) recognized that use of industrial or domestic waste can improve some properties of fresh and hardened concrete. Tam and Tam (2006) opined that technology that will enable building materials to be progressively infused with recycled plastic constituent, which would lead to increase strength, durability and impact resistance, as well as enhance appearance is being developed.

The reuse of waste, especially plastic waste helps to save and sustain natural resources, (in this case natural sand) which are not replenished (Ismail and AH-Hasmi, 2008). Ravikumar and Manjunath (2015) investigated aggregate replacement in concrete and established that river sand can be replaced with manufactured sand completely, and with the addition of plastic fibres without any adverse effect on the mechanical properties of the concrete. The use of plastic fibres rather improves the mechanical properties of concrete. The use of recycled plastic waste as partial replacement for fine aggregate in concrete was investigated to have positive effect on the strength properties of concrete (Harini and Ramana, 2015). Kandasamy and Murugesan (2012), however, posited that increase in the mechanical properties of concrete mixed with polythene fibres is not in the range of that of steel fibres.

Since workability affect the quality of concrete, and the characteristics of concrete constituent materials affect workability, it is therefore important that an assessment is conducted to study the effect of partial replacement of fine aggregate on the this important parameter of fresh concrete for strength, durability and ultimate performance of the concrete. This article therefore, reports the results of the investigation of the effect of partial replacement of sand with granulated plastic waste on strength characteristics such as workability, compacting factor, compressive strenth, water absorption and density of concrete.

2.0 MATERIALS AND METHODS

Ordinary Portland Cement (OPC) with specific gravity of 3.15, conforming to BS 12 (1996) and ASTM C 150 -12 (2013), which is commercially available, was used for this study. The fine aggregate for the concrete is normal sand obtained from Gidan Kwano Village, Minna. Granulated waste plastic was obtained from old/discarded waste water tank obtained from a dump site in Maitumbi, Minna, Niger State, Nigeria. The waste water tank was granulated to a texture suitable as fine aggregate in concrete according to BS 882 (1992). Clean water from Civil Engineering Laboratory, Federal University of Technology Minna, Nigeria was used for the concrete in this work. The water was suitable according to BS 3148, (1980). Crushed granite stone with nominal size 5mm to 20mm, suitable according to BS 882 (1992) was used as coarse aggregate. Sieve size analysis was conducted in accordance to BS 1377 (1990).

A nominal mix ratio of 1:2:4 for Cement: Fine Aggregate: Coarse Aggregate, and water-cement ratio of 0.55 was used for this work. Absolute volume method was adopted for mix composition for concrete ingredients according to (1). Each mixture consisted of 385 kg/m^3 cement, 728 kg/m^3 sand, 1537 kg/m^3 gravel.

$$V = \frac{W_w}{1000} + \frac{W_C}{1000SG_C} + \frac{W_{FA}}{1000SG_{FA}} + \frac{W_{CA}}{1000SG_{CA}} + Va = 1(m^3) \quad (1)$$

where:

W_w = Weight of water (Kg); W_C = Weight of cement (Kg); W_{FA} = Weight of sand or plastic (Kg); W = Weight of coarse aggregate (Kg); SG_C = Specific Gravity of cement (3.15); SG_{FA} = Specific Gravity of fine aggregate (sand/cement (2.63/2.22); SG_{CA} = Specific Gravity of coarse aggregate (2.65); Va = Volume of air entrapped in concrete (2%; Neville and Brook, 1987)

2.1 Casting and Testing of Concrete Specimen

The calculated volumes of concrete ingredients were measured and mixed thoroughly to obtain homogenous mix. The slump of the concrete was measured using and inverted frustum of 300mm in accordance to BS 1881: Part 102 (1983). Composition/batching and mixing of the concrete was conducted according to BS 1881: Part 108, (1983). In addition to the common workability tests namely Slump and compacting factor, other tests carried out include particle size distribution, dry density test, and specific gravity test in accordance with BS 1377 (1990).

3.0 RESULTS AND DISCUSSION

3.1 Properties of the Aggregate

Table 1 shows the result of some of the properties for the aggregates used. With the exception of granulated plastic, which recorded a lower value of specific gravity, the values obtained are within the range specified for concrete aggregates, that is 2.60 – 2.70 (Neville, 2003; Olanipekun, *et al*. 2006). Water absorption for sand, gravel and plastic granules is also shown in Table 1. The absorption of aggregates influences the bond between it and the cement paste. Water absorption for sand, gravel and plastic granules is 24.18 (%), 13.11 (%) and 18.26 (%) respectively. Water absorption of granulated plastic was initially higher that the absorption of gravel. However, after 10% replacement, the absorption reduces below that of gravel. This may be explained by the hydrophobic property of plastic, which resulted to inability of plastic fibre to absorb water even in the presence of other binder such as cement during the process of hydration and/or coagulation.

Granulated plastic has lesser density than gravel and much lesser than the density of sand. In addition to this, concrete with partial replacement of fine aggregate with granulated plastic has average dry density of 1752 kg/m^3, which is within the range stipulated for structural lightweight concrete (1440 – 1840 kg/m^3), in accordance with BS 8110 (1997).

Table 1: Properties of Aggregates used

Properties	**Sand**	**Plastic granules**	**Gravel**
Loosed Bulk Density (g/cm^3)	1570	587.1	1451.8
Compacted Bulk Density(g/cm^3)	1683	665.2	1680.2
Ratio of Loosed Bulk Density to Compacted Bulk Density (g/cm^3)	0.93	0.9	0.9
Specific Gravity	2.63	2.22	2.65
Water Absorption (%)	24.18	18.26	13.11

3.2 SIEVE ANALYSIS OF SAMPLES

The result of sieve size analysis for the aggregates used is shown in Figure 1. The grading curves of these aggregates fall within the lower and upper limit of the grading requirement for naturally sourced aggregates according to (BS 882, 1992; Neville 2003; Neville and Brook 1987). Poorly-graded silty-sand (Class SP). The gradation of the crushed aggregate is below the lower limit requirement, but the deficiency was taken care of by increase percentage of fines in the granulated plastic as indicated in Figure 1.

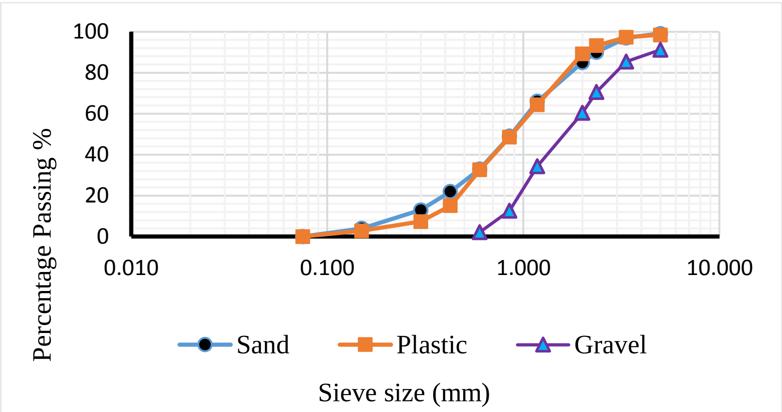

Figure 1: **Sieve Analysis for the Aggregates used**

3.3 THE SLUMP TEST OF FRESH CONCRETE

The slump of fresh concrete made with sand partially replaced with plastic granules in predetermined proportions is shown in Figure 2, while the workability is shown in Table 2. The lowest slump is 15mm at 0% replacement while 55mm was the highest slump at 15% replacement. The slump of the fresh concrete therefore is from very low to medium.

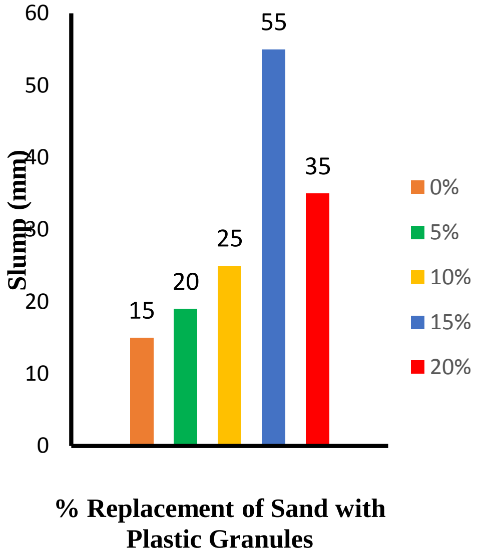

Figure 2: The Slump of Fresh Concrete

Table 2: The Slump and Workability of Fresh Concrete

Replacement of sand with plastic (%)	Concr. Mix	Water/ Cement ratio	Slump (mm)	Degree of Workability
0	1:2:4	0.55	15	Very low
5	1:2:4	0.55	20	Very low
10	1:2:4	0.55	25	Low
15	1:2:4	0.55	55	Low
20	1:2:4	0.55	35	Low

3.4 COMPACTING FACTOR OF CONCRETE

The compacting factor of fresh concrete made with 0%, 5%, 10%, 15% and 20% replacement of fine aggregate with granulated waste plastic for the adopted nominal concrete mix of 1:2:4 is shown in Figure 3. The compacting factors obtained are 0.92, 0.93, 0.97, 0.99 and 0.96 for concrete cast with 0%, 5%, 10%, 15%, and 20% replacement of sand with granulated plastic respectively. Compacting factor initially increase with percentage replacement from 0 – 15%, but later reduces at 20 %. The interface of plastic waste and its distribution in the evolving mortar matrix, led to reduction of the voids in both fine and coarse aggregate.

The foregoing affects the water absorption capacity of concrete made with sand partially with waste plastic granules. In fact, the water absorption of fresh concrete further decrease after 10% replacement. This finding agrees with the submission of Sikalidis *et al*., (2002); Avila and Duarte, (2003); Ferreira *et al*., (2012), Siddique *et al*. (2008) and Youcef *et al*., (2014) on the use of waste plastic in concrete.

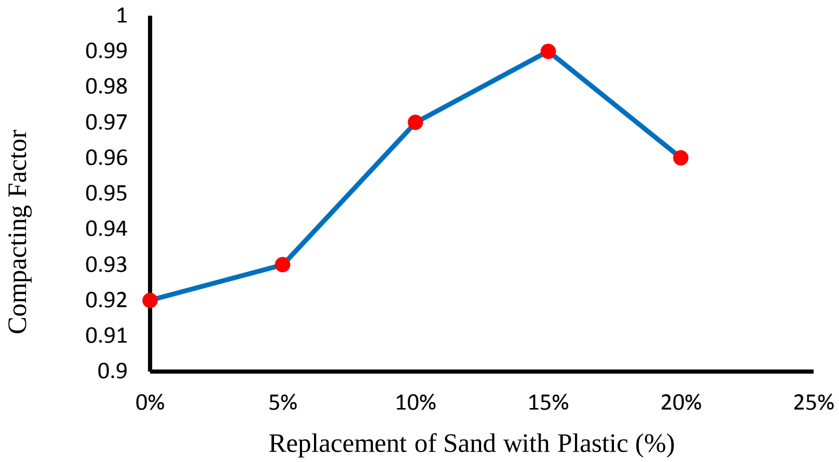

Figure 3: Compacting Factor of Concrete with Plastic Granules Partially Replaced Sand

3.5 COMPRESSIVE STRENGTH AND DENSITY OF PARTIALLY REPLACED CONCRETE

The compressive strength of concrete after 28 days curing showed that concrete with granulated plastic partially replacing sand is lower than the controlled specimen (0 % replacement). This trend may be attributed to decrease in adhesion between the cement paste and the surface of the plastic granules during the hydration process of cement. This affected the bonding process and weakened the cohesion and reduced the strength of the resulting concrete. The average compressive strength developed by concrete cubes with 0%, 5%, 10%, 15%, and 20% replacement of sand with plastic granules after twenty-eight days curing is 27.50 N/mm^2, 24.70 N/mm^2, 26.22 N/mm^2, 19.19 N/mm^2 and 21.82 N/mm^2 respectively Figure 4. The compressive strength development with curing age is shown in Figure 5. Concrete with 0% replacement has the highest twenty-eight day compressive strength of 27.5 N/mm^2 with 20% recording the lowest strength of 20.1 N/mm^2. However, 10% replacement has a lower initial strength with curing age, but later the strength increased and surpassed that of 5% replacement after twenty-eight day curing. Amongst other things therefore, 10% replacement may be assumed as the optimum percent replacement of sand by plastic granules from this investigation.

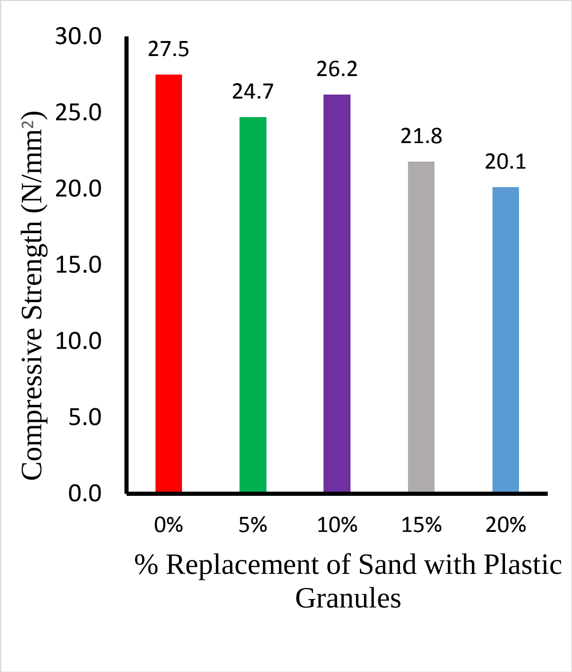

Figure 4: Compressive Strength of Concrete with Plastic Granules Partially Replaced Sand

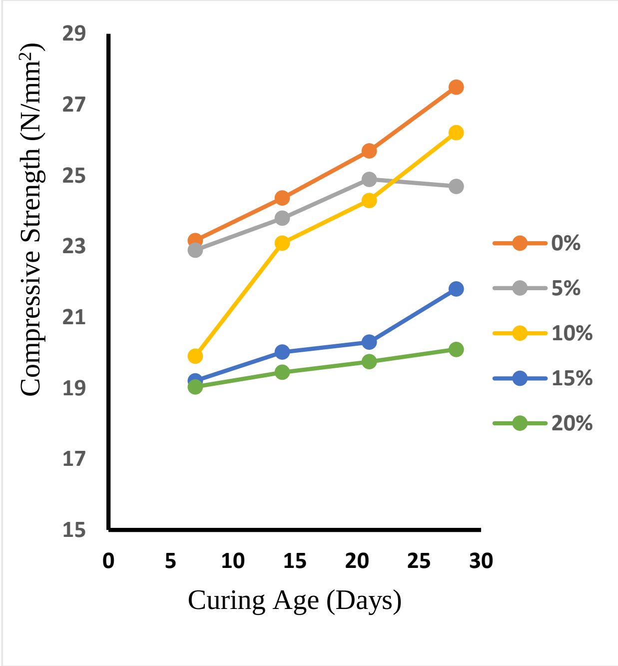

Figure 5: Compressive Strength with Curing age of Concrete with Plastic Granules Partially Replaced Sand

The compacted bulk density of 0% replacement of sand with plastic granules is higher than those in which the sand is replaced. This may be due to the fact sand on its own without interfacing with plastic is densely packed together. The particles of granulated plastic are loosely packed with more void to be filled with sand and cement during chemical reaction for bonding. With coarse aggregates, the void is even greater requiring more mortar. The bulk densities of 10% replacement is higher than 5% and 15% replacement. Further increase in replacement to 20% yielded a reduction in the compacted bulk density of the concrete Figure 6.

Concrete with partial replacement of sand with plastic granules has average dry density of 1752 kg/m^3. This value is within the range stipulated for structural lightweight concrete; 1440 – 1840 kg/m^3 (BS 882, 1992). The bulk densities of compacted sample are 1683.16 kg/m^3 for sand, 1680.20 kg/m^3 for coarse aggregates and 665.16 k/m^3 for plastic granules. The average dry density of concrete with plastic granules partially replaced sand is shown in Figure 7.

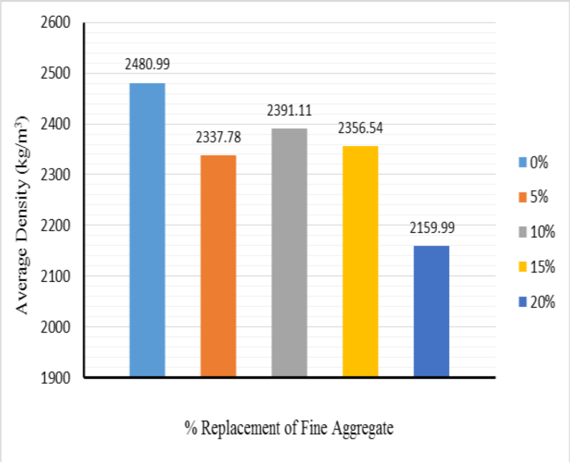

Figure 6: Bulk Density of Concrete with Plastic Granules Partially Replaced Sand

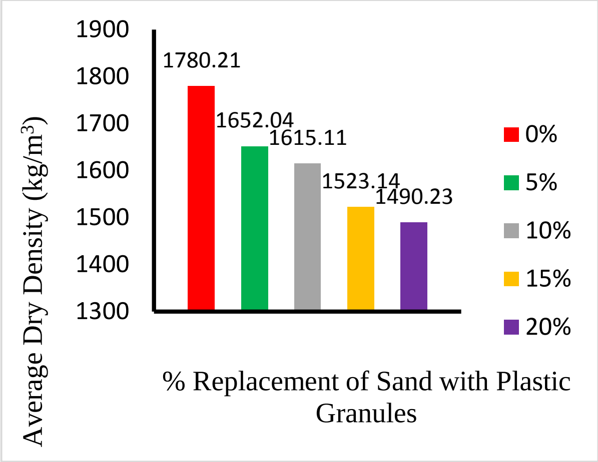

Figure 7: Dry Density of Concrete with Plastic Granules Partially Replaced Sand

4.0 CONCLUSION

The main conclusions drawn from the investigation on the effect of partial replacement of fine aggregate with granulated plastic on workability and compaction characteristics of concrete are:

Increase in partial replacement of sand with granulated plastic from 5 – 15 % yielded increase in compacting factor of fresh concrete. However, further increase to 20% led to decrease in compacting factor.

The slump of fresh concrete increases with increment in percent partial replacement of fine aggregate with granulated waste plastic.

Granulated plastic has lesser density than gravel and much lesser than sand. In addition to this, concrete with partial replacement of sand with granulated plastic has average dry density of 1752 kg/m^3, which is within the range stipulated for structural lightweight concrete (1440 – 1840 kg/m^3). Therefore, concrete with plastic granules as partial replacement for sand may be suitable for lightweight structural applications.

Concrete with 0% replacement has the highest twenty-eight day compressive strength of 27.5 N/mm^2 with 20% recording the lowest strength of 20.1 N/mm^2. Therefore the higher the percent replacement of sand with plastic granules, the lower the strength.

Compacting factor initially increase with percentage replacement from 0 – 15%, but later reduced at 20 %. This may be responsible for the ease of compaction and reduction in strength at higher percentage replacement.

Water absorption of plastic is low compared with that of sand. Increase in percent replacement of sand with granulated plastic yielded increase in the workability and compaction characteristic of fresh concrete.

REFERENCES

ASTM C150 - 12 (2013). Standard Specification for Portland Cement. American Society for Testing and Materials.

Avila A. F. and Duarte, M. V. (2003). A mechanical analysis on recycled PET/HDPE composites, *Polym Degrade. Stabil*, 80(2), 373–82.

BS 12:1996 - Specification for Portland cement. BS EN 197 -1: 2000; British Standards Institution, London.

BS 8110-2 (1997). Structural Use of Concrete, British Standards Institution, London.

BS 1377 (1990). Methods for test for soils for civil engineering purposes, In-situ tests, BS 1377-9. British Standards Institution, London.

BS 3148 (1980). Methods of test for water for making concrete. British Standards Institution, London.

BS 882 (1992). Specification for aggregates from natural sources for concrete. British Standards Institution, London.

BS 1881: Part 108, (1983), Method for making test cubes from fresh concrete. British Standards Institution, Her Majesty Stationery Office, London.

BS 1881: Part 102, (1983), Method for determination of slump. British Standards Institution, Her Majesty Stationery Office, London.

Dugal, S. K. (2010). Building Materials; Third Revised Edition, Macmillan Education Limited, Honkong.

Edward, G. N. (2008). Concrete Construction Engineering Handbook, Second Edition, The State University of New Jersey, New Brunswick, New Jersey, CRC Press Taylor & Francis Group, 1-11.

Ferreira, L., Brito, J. D. and Saikia, N. (2012). Influence of Curing Conditions on Mechanical Performance of Concrete Containing Recycled Plastic Aggregate. *Constr. Build. Materials*, 36, 196–204.

Harini, B. and Ramana K. V. (2015). Use of Recycled Plastic as Partial Replacement for fine Aggregate in Concrete, *International Journal of Innovative Research in Science*, 4(9), 8596-8603.

Ismail, Z. Z. and Al-Hashmi, E. A. (2008). Use of waste plastic in concrete mixture as aggregate replacement, ScienceDirect, Elsevier, *Waste Management*, 28, 2041–2047

Kandasamy, R. and Murugesan.R (2012). Fibre Reinforced self-compacting concrete using domestic waste plastics as fibres, *Journal of Engineering and applied science,* 7, 405-410.

McGinley, T. J. and Choo, B. S. (1990). Reinforced Concrete Design; Theory and Examples. Second Edition; E&FN Spon, Chapman and Hall, London.

Neville, A. M., (2003) Properties of Concrete, Fourth Edition, India.

Neville, A. M. and Brook J. J. (1987). Concrete Technology, Longman group, Pearson Educational Publisher, New Longman House, Burnt mill, Harlow, Essex CM702JE, England.

Olanipekun, E. A., Olusola, K. O., and Ata, O. A., (2006), Comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates, *Building and Environment*, 41(3), 297 – 301.

Olawuyi, A. D. (2010). Blast Furnace Slag as Aggregate for Concrete, *Building Science*, 10,135-141.

Ravikumar, G., Manjunath, M. (2015). Investigation on Waste Plastic Fibre Reinforced Concrete using Manufactured Sand as Fine Aggregate, *International Research Journal of Engineering and Technology*, 2(4), 183-186.

Salawu, G. O. (2007). Effect of Locally Available Materials on Concrete Properties, *In-House Seminar Paper*, Nigerian Building and Road Research Institute.

Shetty, M. S. (2004). Concrete Technology, Fifth Edition, Chand and Company Limited, 7361 Ram Nagor, New Delhi, India.

Siddique R, Khatib, J. and Kaur, I. (2008). Use of recycled plastic in concrete: A Review, *Waste Management*, vol. 28, 1835–1852.

Sikalidis, C. A., Zabaniotou, A. A. and Famellos, S. P. (2002). Utilization of Municipal Solid Wastes for Mortar production, *Resources Conservation Recycling*, 36(2),155–167.

Youcef, G., Bahia, R., Brahim, S. and Rabah, C. (2014) *Journal of International Scientific Publications*: Materials, Methods and Technologies, Vol. 8, ISSN 1314-7269, 480-487.

Tam, V. W. Y. and Tam, C. M., (2006). A Review on the Viable Technology for Construction Waste Recycling, *Resources Conservation & Recycling*, 47, 209–221.