CARD International Journal of Engineering and Emerging Scientific Discovery
ISSN: 2536-7250 (Print): 2536-7269 (Online)
Volume 2, Number 1, March 2017
http://www.casirmediapublishing.com

Durability of Waste Metal Bottle Caps Aggregate Concrete

Egbe-Ngu Ntui Ogork [1] and Daud Gussau Haruna [2]
[1,2] Department of Civil Engineering
Bayero University, PMB 3011, Kano, Nigeria
Email: egbenguogork@yahoo.com[1], harunagusau65@yahoo.com[2]

ABSTRACT

This paper assessed the effects of Waste Metal Bottle Caps (WMBC) aggregates on the durability characteristics of concrete. WMBC used were obtained from local drinking points in Kano, Nigeria. The WMBC were prepared with its edges folded with hammer and plier and characterized for use in concrete of 1:2:4 mix ratio and water cement ratio of 0.55 containing WMBC aggregates as partial substitute of granite aggregate of 0, 10, 20, 30, 40 and 50% respectively. A total of seventy two (72) number 100 mm x 100 mm x 100mm cubes of hardened concrete were tested for compressive strength at the age of 3, 7, 28, 56 days of curing in accordance with standard procedure. Crushed samples of the cubes of WMBC concrete from the compressive strength test at 28 days curing for the six mixes were weighed and exposed in 5 % concentration of sulphuric acid (H_2SO_4) medium and weight retained recorded at 7 days interval until the 28th day, to determine the resistance of WMBC concrete to sulphuric acid aggression. Also, eighteen number 100 mm x 100 mm x 100 mm cubes of WMBC concrete were tested for water absorption at 28 days curing. A total of thirty six number 100 mm x 100 mm x 100 mm cubes of WMBC concrete cured for 28 days were subjected to elevated temperature of 200 °C for 1 and 2 hours, respectively and were also tested for compressive strength. The results of the investigations showed that WMBC aggregates were predominantly of Fe_2O_3 (97.7 %), smooth but denser than normal aggregates. The compressive strength and water absorption of concrete containing WMBC aggregate decreased with increase in WMBC content. However, up to 30 % WMBC could be suitable for partial substitution of coarse aggregate in concrete in normal environment. The resistance of up to 20 % WMBC concrete exposed to sulphuric acid environment is similar to that of normal aggregate concrete and slightly lower for higher content of WMBC aggregates. WMBC concrete exposed to elevated temperature experienced higher compressive strength loss than that of concrete made with crushed granite aggregate. The compressive strength loss of WMBC concrete at elevated temperature range from 8.9 % to 22 % and 22 % to 39.1 %, as opposed to compressive strength loss of control samples of 2.9 % and 10.3 %, for 1 and 2 hours exposure respectively.

Keywords: WMBC, Aggregate, Concrete, Durability.

INTRODUCTION

As a common construction material, concrete has been widely applied in various environmental conditions, for example, marine environment and cold regions. Over, the past few decades, the durability problems of reinforced concrete structures have been recognized and have become the subject of ongoing research. One of the key issues of durability associated study is to investigate the transport properties of concrete when exposed to aggressive environment (Shi *et al.*, 2012). The durability and stability of concrete when exposed to various environmental conditions are the factors that put concrete ahead of other construction materials (Neville, 2003). The durability of concrete is an important property which significantly determines the service life of concrete structures (Turkel *et al.*, 2007). It is a measure of the ability of concrete structures to withstand the environmental conditions to which it is exposed. According to Yuksel *et al.* (2007), durability of concrete is its ability to resist chemical and physical attacks that lead to deterioration of concrete during its service life. These attacks include leaching, sulphate attack, acid attack, carbonation, alkali-aggregate reaction, freezing- thawing and abrasion. Though compression strength of concrete is a measure of durability to a certain extent, but it is not entirely true that strong concrete is always durable, owing to some failure observed of concrete of high compressive strengths due to environmental conditions (Ogork *et al.*, 2010).

Recently, it has been gradually admitted that all of the deterioration processes of concrete are resulted from the existence of the internal damage or cracking (that is, cracks or micro cracks) and the insufficiency of the concrete structures, for example, thin concrete cover. Cracking within concrete, possibly induced by external loading, drying shrinkage, thermal deformation, or chemical attack, not only affects its mechanical behavior but also influences the efficacy of concrete as a barrier against aggressive agents because cracks significantly modify the tortuosity and continuity of the pore structure of concrete (Mu *et al.*, 2013).

The permeability of concrete may be the most relevant concrete property affecting its durability because it relates the problems associated with long-term exposure to an aggressive environment. So, it is also important to investigate it when determining the effect of larger sized coarse aggregates and Microsilica on the durability of concrete. Sasatani *et al.* (1995) found that Microsilica concrete showed the lowest chloride permeability when compared to ordinary Portland cement concrete and concrete containing other admixtures. The addition of Microsilica decreases the volume of pores within the concrete, thereby reducing the penetration of chloride ions into the concrete and preventing corrosion (Malhotra and Mehta, 1996).

The growing concern of resources depletion and global pollution has challenged many researchers to seek and develop new materials for concrete, relying on renewable resources. Sustainable growing has been a key concept for development of concrete formulation in last decades. These include the use of industrial sub-products and waste materials in building construction (Siddique, 2008 and Winkler, 2010). According to Kutegeza and Alexander (2004), the use of waste material as aggregate in the utilization of concrete production is sustainable and provides several advantages; lowering the cost of construction, land space used for disposal is decreased and existing natural aggregate sources are not as quickly depleted and could be made available for the future generation.

The use of waste metal bottle caps (WMBC) as partial substitute of coarse aggregates for the production of concrete is one means of achieving a more environmentally friendly concrete. This reduces the consumption of the available natural aggregates. In Nigeria and most developing countries, some regions such as large urban areas experience problems in obtaining adequate supplies of natural coarse aggregates at appropriate cost. However, increasing quantities of waste metal bottle caps from drinks bottling companies is generated as waste material in these areas such as large urban areas and is traditionally dumped as waste in landfills. Ogork and Haruna (2016) have reported on the possible use of WMBC as partial substitute of conventional aggregate in concrete. This research sets to investigate on the durability characteristics of concrete containing WMBC as partial coarse aggregate.

MATERIALS AND METHODS

Materials

Ordinary Portland cement (Dangote brand) was used. Sand used for the study was collected from River Challawa, Kano, Nigeria. The particle size distribution of the sand is shown in Figure 1.The coarse aggregate used was crushed granite of nominal size of 20 mm. The particle size distribution is also shown in Figure 1.

Waste metal bottle caps (WMBC) were obtained from selected points in Kano and two of the WMBC were fastened together and shaped manually using plier and hammer to form the WMBC for use as aggregate as shown in Plate 1. The grain size distribution is also shown in Figure 1. A chemical composition analysis of the WMBC aggregates was conducted using X-Ray Flouresence (XRF) analytical method and shown in Table 2.

Plate 1: Waste Metal Bottle Caps Aggregate.

Methods

Concrete mix proportion

Concrete of 1:2:4 mix ratio and water-cement ratio of 0.55 was used to assess the durability of WMBC as partial replacement of coarse granite aggregates in concrete. Six mixes were used; CM-00 is the control mix and CM-10, CM-20, CM-30, CM-40 and CM-50 are mixes with WMBC content of 10, 20, 30, 40 and 50 %, respectively as partial substitute of coarse granite aggregates

Compressive strength test on WMBC-concrete

The compressive strength of Concrete with WMBC aggregates was carried out in accordance with BS EN 12390, Part 3 (2009) for concrete of 1:2:4 mix ratio and water-cement ratio of 0.55. A total of seventy two (72) number 100 mm x 100 mm x100 mm cube specimens were cast and cured in water for 3, 7, 28 and 56 days. At the end of every curing time, compressive strength was determined in accordance BS EN 12390, Part 3 (2009).

Test of WMBC-Concrete Resistance in Acidic Environment

This was carried out using crushed samples of the cubes of WMBC-concrete from the compressive strength test at 28 days curing for the six mixes. Three pieces of crushed samples for each percentage replacement of WMBC were taken and weighed before immersion in 5 % concentration of sulphuric acid (H_2SO_4) solution. The concrete specimens were weighed after subjection in acid environment at 7 days interval until the 28th day to determine the weight of the samples after the acid attack.

Water Absorption Test

Water absorption test was conducted on 100 mm x 100 mm x 100 mm WMBC-concrete cubes in accordance with BS EN 12326-2 (2002). A total of eighteen (18) number samples of concrete were cast and cured for 28 days and weighed before drying in a hot air oven at 105 °C. The drying process was continued, until the difference in mass between two successive measurements at a 24 hour interval closely agreed. The dried specimens were cooled at room temperature and then immersed in water. The specimens were taken out at regular intervals of time, surface dried and weighed. The difference between the saturated mass and the oven dried mass expressed as a percentage of the oven dried mass gives the saturated water absorption. The specimens were tested in triplicate to obtain an average.

Test of WMBC-Concrete Resistance to Elevated Temperature

The test was conducted on 100 mm x 100 mm x 100 mm WMBC-concrete cubes in accordance with BS 8110 - 2 :1985. A total of thirty six (36) number samples of concrete were cast and cured for 28 days in clean water and after surface dried were subjected to temperature of 200°C in a ventilated oven for 1 and 2 hours, respectively and the compressive strength of the sampled determined after cooling to ambient temperature. The results were compared with that from eighteen number other samples which were not subjected to elevated temperature and tested at ambient temperature of 24 °C and relative humidity of 57 %, as control.

RESULTS AND DISCUSSION

Properties of Concrete Constituent Materials

Table 1: Physical Properties of Constituent Materials

Property	Cement	Sand	Crushed granite	WMBC
Specific gravity	3.15	2.55	2.71	3.75
Moisture content (%)	-	2.50	1.45	-
Aggregate crushing		-	26	0
Aggregate impact value		-	22	0

Table 2: Oxide Composition of WMBC

Oxide (%)	CaO	Sc_2O_3	TiO_2	Cr_2O_3	MnO	Fe_2O_3	CuO	Ta_2O_3	PbO
WMBC	0.23	0.042	1.16	0.07	0.22	97.7	0.030	0.03	0.27

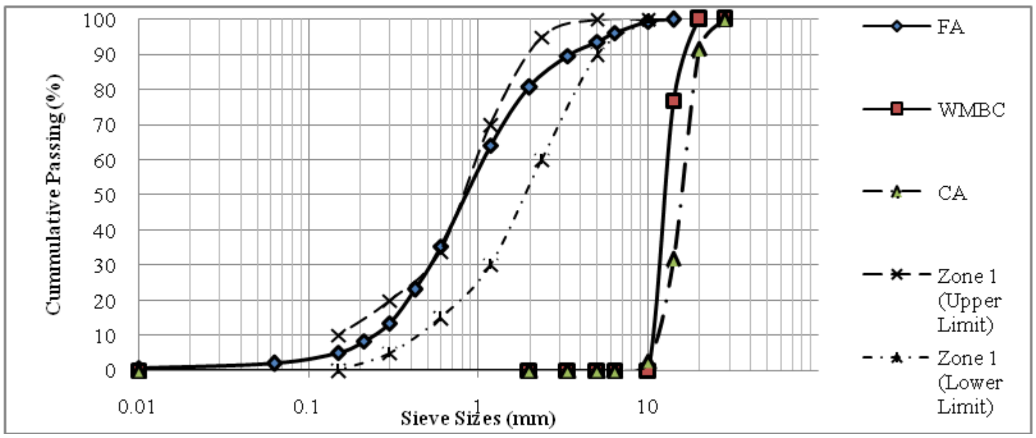

Figure 1: Particle size distribution of fine, coarse, and WMBC aggregates

The grain size distribution of sand indicated that the sand used was classified as zone -1 based on BS 882 (1992) grading limits for fine aggregates.

WMBC aggregates with a specific gravity of 3.75 when compared with crushed granite aggregates of specific gravity of 2.71 indicated that the WMBC concrete would be denser than that made with crush granite. The WMBC aggregates impact and crushing values of 0 % also showed better resistance to impact force than the crush granite aggregates with impact and crushing values of 22 and 26 %, respectively. The oxide composition of WMBC aggregates (Table 2) indicated that it is predominantly of Fe_2O_3 (97.7 %). This may make WMBC concrete more susceptible than concrete with normal aggregates in aggressive environments. The smooth surface of WMBC aggregates may also adversely affect the compressive strength of WMBC concrete due to poor bond of WMBC aggregate and cement paste (Neville, 2003).

Compressive Strength of WMBC Concrete

Figure 2 shows the compressive strength behavior of WMBC concrete, and indicated increase in compressive strength with age of curing due to cement hydration, and decrease in compressive strength with increase in WMBC content. The decrease in compressive strength with increase in WMBC content may be attributed to the smooth surface of WMBC which may impede the bonding between the WMBC and the cement paste (Neville, 2003; Mather, 2004). The results indicated that up to 30 % WMBC is suitable for partial substitute of coarse aggregate, with a 28days compressive strength of concrete of 20 N/mm^2 which has satisfied the strength requirement specified in BS 8110-1 (1997).The 56 days compressive strength of WMBC concrete ranged from 15.7 to 30.7 N/mm^2, with highest strength at 0 % WMBC content (control).It was also found that the density of WMBC concrete was within the range of that for normal concrete of 2200 kg/m^3 to 2600 kg/m^3 as stated in Neville (2003). However, the density of concrete with high content of WMBC was largely higher than that of concrete with normal aggregates.

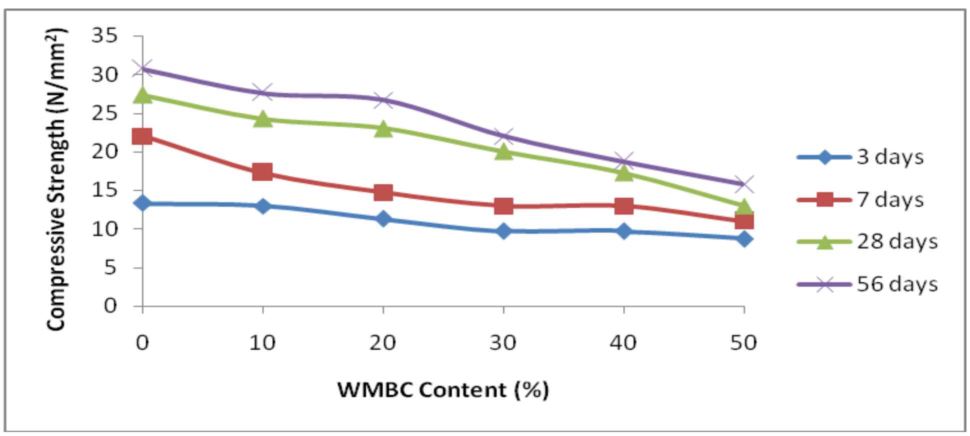

Figure 2: Compressive strength of concrete at varying WMBC content

Resistance of WMBC Concrete in Sulphuric Acid Medium

The resistance of concrete containing WMBC exposed to 5% concentration of sulphuric acid medium as shown in Figure 3 indicated a decrease in resistance of the concrete in terms of weight retained with increase in duration of exposure in sulphuric acid medium. Concrete containing up to 20% WMBC showed similar resistance to the acid attack with that of control samples. However, there was slight decrease in resistance to acid attack in the case of concrete containing WMBC of 30% to 50% replacement (96.9 to 99.2 % of resistance of control samples). It was also observed that the WMBC in the concrete suffered some corrosion when subjected to the acidic environment and this is in agreement with El-Hadi and Tantawi (2002) on corrosion of reinforced steel in different media with attendant loss in compressive strength.

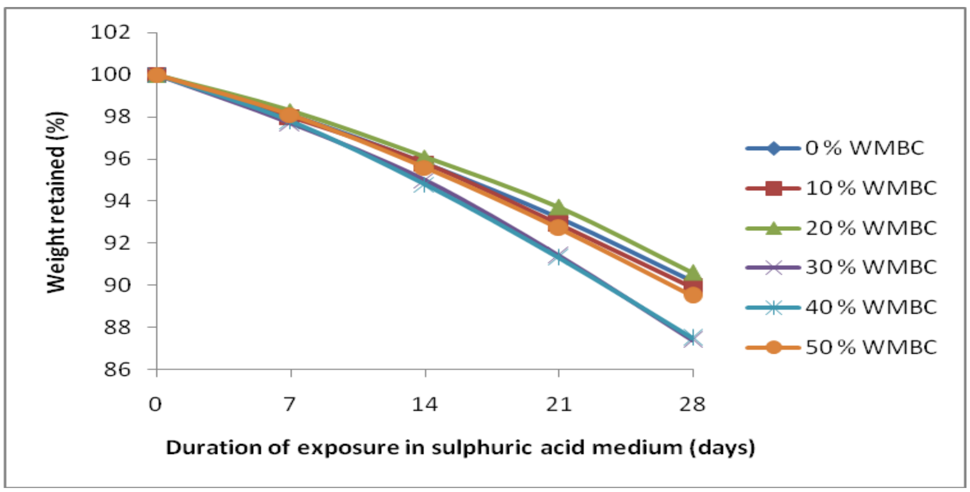

Figure 3: Resistance of Concrete containing WMBC Exposed to 5% Concentration of Sulphuric Acid Medium

Water Absorption of WMBC Concrete

Figure 4 showed the water absorption characteristics of WMBC concrete, and indicated decrease in water absorption with increase in WMBC content. The water absorption of WMBC concrete ranged from 28.6 to 93.4 % of that of control samples (0 % WMBC), with least water absorption at 50 % WMBC content. The decrease in water absorption is due to the low porosity of WMBC embedded in concrete. This implied that WMBC as partial coarse aggregate in concrete will perform as good durable material in concrete in an environment that is associated with repeated freezing and thawing or wetting and drying cycles which can cause volume change in concrete. This is consistent with Holm *et al.* (1984) and Vieira (2003) works on porosity of lightweight aggregate concrete.

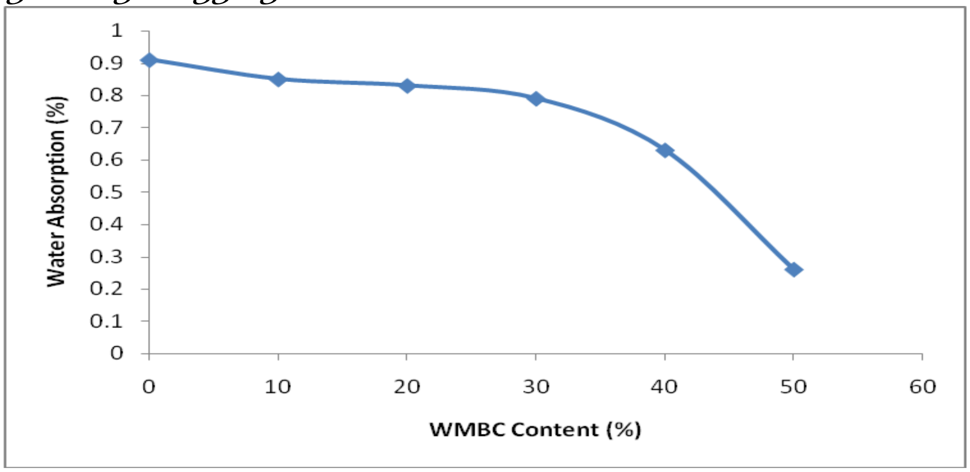

Figure 4: Effect of WMBC on Water Absorption of Concrete.

Resistance of WMBC Concrete Subjected to Elevated Temperature

Figure 5 showed the 28 days compressive strength of WMBC concrete at ambient temperature of 24°C and at elevated temperature of 200 °C for 1 and 2 hours, respectively. The results indicated a decrease in compressive strength of concrete with increase in WMBC content at ambeint and elevated temperatures. The compressive strength loss of control samples (0 % WMBC) at elevated temperature when compared to that at ambient temperature was 2.9 % and 10.3 %, for 1 and 2 hours exposure, respectively. However, the compressive strength loss of WMBC concrete at elevated temperature when compared to that at ambient temperature range from 8.9 % to 22 % and 22 % to 39.1 %, for 1 and 2 hours exposure, respectively. The highest compressive strength loss of the WMBC concrete to elevated temperature was experienced with concrete containing 50 % WMBC. The loss in strength may be attributed to the poor resistance of the WMBC subjected to high temperatures, consistent with Metin (2006) work on the effect of high temperature on compressive strength of concrete.

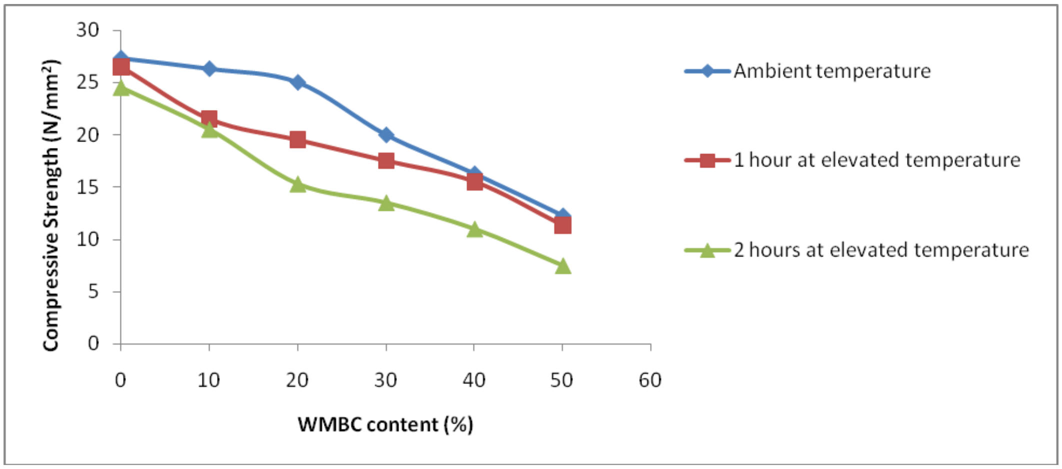

Figure 5: Resistance of WMBC Concrete Subjected to Elevated Temperateure

CONCLUSIONS

i) WMBC aggregates are predominantly of Fe_2O_3 (97.7 %), smooth but denser than crushed granite aggregates.

ii) The compressive strength of WMBC concrete decreased with increase in WMBC content. However, up to 30 % WMBC would be suitable for partial substitution of coarse aggregate in concrete in normal environment.

iii) The resistance of up to 20 % WMBC concrete to sulphuric acid environment is similar to that of granite aggregate concrete and slightly lower for higher content of WMBC aggregates

iv) The water absorption of WMBC concrete decreased with increase in WMBC content.

v) WMBC concrete exposed to 1 and 2 hours of elevated temperature experienced higher compressive strength loss than that of concrete made with crushed granite aggregate.

REFERENCES

BS 882-2 (1992) Grading limits for fine aggregates, British Standard Institution, London, United Kingdom

BS 8110-2: 1985: Structural use of concrete, designed to possess an appropriate degree of resistance to flame penetration, heat transmission and collapse, British Standard Institution, London, United Kingdom

BS 8110-1 (1997) Structural use of concrete, code of Practice for design and construction, British Standard Institution, London, United Kingdom

BS EN 12326-2 (2002): Methods of Testing Moisture Content for civil Engineering Purposes, Part – 2, British Standard Institute, London, United Kingdom

BS EN 12390-3 (2009) Method for determination of compressive strength of concrete cubes, British Standards Institution, London.

El-Hadi, Z.A. and Tantawi, N.S. (2002): Influence of silica fume on corrosion behavior of reinforced steel in different media. Journal of Material Science and Technology, vol. 18, no. 1, pp. 83-88

Holm, T.A., Bremener, T.W., Newman, J.B. (1984): Lightweight aggregate concrete subjected to severe weathering, concrete International, vol.6, no.6, pp.49-54.

Kutegeza, B. and Alexander, M.G. (2004): The performance of concrete made with commercially produced recycled coarse and fine aggregates in the Western Cape. International Conference on Sustainable Waste Management and Recycling: Construction Demolition Waste. Kingston University, September 2004, (Eds. M.C.Limbaichiya and J.J. Roberts), London: Thomas Telford, pp.235-244.

Malhotra, V. M. and Mehta, P. K. (1996): Pozzolanic and Cementitious Materials, Gordon and Breach Publishers, Amsterdam, The Netherlands.

Mather, B. (2004): Concrete Aggregate, Shape Surface Texture and Coatings, vol. 223, ACI Special Publication, Farmington Hills, USA

Metin, H. (2006): The effects of high temperature on compressive and flexural strengths of Ordinary and high- performance concrete, Fire safety journal, pp. 155-163

Mu, S., Schutter, G. and Ma, B. G. (2013): Non-steady state chloride diffusion in concrete with different crack densities, Materials and Structures, vol. 46, no. 1-2, pp. 123-133.

Neville, A.M. (2003): Properties of Concrete, Fourth and Final Edition, Pearson Education (Publisher) Ltd, Indian Branch, 482 P.I.E Patarganj, Delhi 110092. Indian

Ogork, E. N., Aboshio, A. and Balami, D.A. (2010): Durability assessment of concrete made with rice husk ash as admixture. Journal of Engineering and Technology (JET), Faculty of Engineering, Bayero University, Kano, Nigeria, vol. 5, no. 1, pp. 90-98

Ogork, E.N. and Haruna, D.G. (2016): Mechanical Properties of Concrete made from Waste Metal Bottle Caps as Partial Replacement for Coarse Aggregate. Proceedings of 2nd National Engineering Conference on Bridging the Gap between Academia and Industry in Nigeria-Refocusing the Engineering Discipline- 2, Organized by Faculty of Engineering, Bayero University, Kano, Nigeria 6th – 8th December 2016, pp. 290-296

Sasatani, T., Torii, K. and Kawmura, M. (1995): Five Year Exposure Test on Long-Term Properties of Concretes Containing Fly Ash, Blast-Furnace Slag and Silica Fume in Concrete. Proceedings, Fifth International Conference, Milwaukee, WI (Vol. I), Malhotra V.M. (editor), American Concrete Institute, Detroit, MI, pp. 283-296.

Shi, X., Xie, N., Fortune, K., and Gong, J. (2012): Durability of steel reinforced concrete in chloride environments: an overview. Construction and Building Materials, vol. 30, pp. 125-138.

Siddique, R. (2008): Waste Materials and by- Products in concrete, Springer-Verlag Berlin Heidelberg.

Turkey, S., Felekoglu, B. and Dulluc, S. (2007): Influence of various acids on the Physico-chemical properties of Pozzolanic cement mortars. Sadhana, vol.32 part 6: pp.683-691.

Vieira, M. (2003): High performance lightweight aggregates. Durability and microstructure, MSc Thesis, TM 18, LNEC, Lisbon, 2003 (in Portuguese).

Winkler, G. (2010): Recycling construction and demolition waste: A LEED based toolkit, McGraw Hill, New York, USA

Yuksel, I., Bilir, T. and Ozkan, O. (2007): Durability of Concrete incorporating non-ground blast furnance slag and bottom ash as fine aggregate. Building and Environment, vol. 42, pp. 2651-2659