EFFECT OF NANO SILICA ON DURABILITY PROPERTIES OF CONCRETES CONTAINING RECYCLED COARSE AGGREGATES

Faiz Uddin Ahmed Shaikh[1] and Heasam Odoh[1]

[1] Curtin University, Dept. of Civil Engineering, Australia
e-mail: s.ahmed@curtin.edu.au

ABSTRACT

This paper presents the effect of nano silica (NS) on durability properties of concretes containing recycled coarse aggregates (RCA). The RCA is sourced from local construction and demolition (C&D) wastes. Seven series of concretes are considered in this study. The first series is the control series which contains all natural aggregates and no NS. In the second and third series, 25% and 50% (by wt.) natural coarse aggregate are replaced by RCA, respectively. The effects of NS on concretes containing RCA are evaluated in rest of the series. In fourth and fifth series, 1% and 2% (by wt.) NS are added in concrete containing 25% RCA, respectively. The sixth and seventh series are similar to fourth and fifth series in every aspect except the RCA content of 50%. Durability properties, such as sorptivity, volume of permeable voids and chloride penetration of above concretes are evaluated after 7 and 28 days of water curing. Results show that the addition of NS significantly improves the above durability properties of concretes containing 25% and 50% RCA.

KEYWORDS: Recycled aggregate, nano silica, durability properties, concrete.

1 INTRODUCTION

The drawbacks exhibited by recycled coarse aggregates (RCA) are attributed to the presence of old mortar/paste and fissures formed during crushing of RCA make the concretes more susceptible to penetration of aggressive substances (Kou et al., 2012 and Etxeberria et al., 2007) and hence impact on the concrete durability properties. From the investigations of the properties of concrete containing RCA at various substitutions, results have shown certain characteristics including a weaker interfacial transition zone between the cement paste and the RCA, and an increase in permeability. Significant research based on mechanical and durability performance of concrete incorporating RCA have recommended a substitution range of 20%-30%, as replacements within this range have been found to show minimal influence on the overall performance of the concrete (Kwan et al., 2012, Kou and Poon, 2012, Thomas et al., 2013, Kou et al., 2011, Shaikh and Nguyen, 2013, Shaikh, 2013), thus highlighting the feasibility and potential to solve the current environmental issues.

Whilst the above findings are significant indicating the feasibility of its incorporation in concrete, the lack of proper jurisdictions to allow its incorporation in structural applications has limited the use of RCA in Australia as a whole. Other researchers have investigated the use of supplementary cementing materials in concrete containing RCA and their results showed reduction in porosity and enhanced properties of the recycled aggregate concrete. Silica fume, Metakaolin and fly ash are amongst the most widely used additives (Ali et al., 2012, Ann et al., 2008 and Ahmed, 2013). Over the recent years a new supplementary cementing material called nano silica (NS) has emerged on the market and has attracted many researchers across different fields, mainly due to its high SiO_2 content and its nano size particles (Shaikh et al., 2014, Supit and Shaikh, 2014, Jo et al., 2007, Supit et al., 2013). Literature suggests that NS reacts with calcium hydroxide of cement hydration and forms C-S-H gel which fills the interconnected pores and alters their distribution. This in turn reduces the porosity of the concrete matrix and increases its permeability resistance. Additionally, it behaves as a nucleus that tightly bonds with cement hydrate forming a stable gel structure which shows closer packing (Ji, 2005). Given the potential indicators in early age strength gain and general refinement to the internal structure, the objective of this research is to investigate the influence of NS addition on the durability properties of concrete containing RCA.

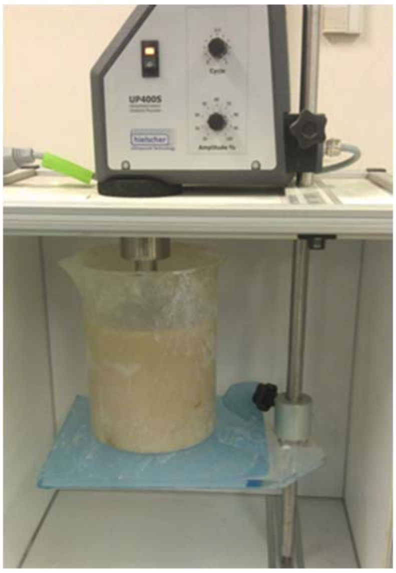

Figure 1: Dispersion of nano silica in water containing superplasticizer during ultra-sonication.

2. EXPERIMENTAL PROGRAM

2.1 Materials

General purpose Portland cement was used in all mixes. Nano silica (NS) was obtained from Nanostructured and Amorphous Materials, Inc. of USA, with average particle diameter of 25 nm and specific surface area of 160 m^2/g. The NS was in powder form with purity of 99% SiO_2. The specific gravity was within the range of 2.2-2.6 (Shaikh et al. 2014). Prior to its addition into the mix, the mix quantity for 1% and 2% NS additive was added into one litre of water containing superplasticizer and was placed in an Ultrasonic dispersion machine shown in Figure 1 for 30 minutes with the aim to evenly disperse the particles and to prevent the formation of NS agglomerates when added to the concrete mix. RHEOBUILD 1000 high range water reducer was added to mixes containing NS at 0.5% of cement for mixes containing 1% NS, and 1% of cement for mixes containing 2% NS. The quantities used are detailed in Table 1 below.

Table 1: Mix proportions of concrete mixes

Series	Mix Proportions (kg/m^3)								Compressive strength (MPa)	
	NS	RCA	NCA (20mm)	NCA (10mm)	FA (Sand)	Cement	Water	Super-plasticizer	7 days	28 days
Control	0.0	0.0	405.0	810.0	654.0	430.0	172.0	0.0	33	46
R25N0	0.0	303.8	303.8	607.5	654.0	430.0	172.0	0.0	29	39
R25N1	4.3	303.8	303.8	607.5	654.0	430.0	172.0	2.2	43	45
R25N2	8.6	303.8	303.8	607.5	654.0	430.0	172.0	4.3	34	53
R50N0	0.0	607.5	202.5	405.0	654.0	430.0	172.0	0.0	26	30
R50N1	4.3	607.5	202.5	405.0	654.0	430.0	172.0	2.2	37	45
R50N2	8.6	607.5	202.5	405.0	654.0	430.0	172.0	4.3	34	38

The recycled coarse aggregate (RCA) was obtained from a local C&D waste recycling plant in Perth, Western Australia. Table 2 shows the analysis of contents of a 5 kg sample of the C&D waste used as RCA in this study. It can be seen that approximately 75% are concrete and the rest consisted of masonry, asphalt and others materials. The properties of recycled and natural aggregates are shown in Table 3. As expected the RCA has higher water absorption, lower bulk density, and more than acceptable amounts of brick content according to Australian Standard (AS- HB 155,2002). However, it met the grading requirements for concrete aggregates specified in the Australian Standards 2758.1 (1998). Both recycled and natural course aggregates were soaked in water for 48 hours and washed thoroughly to remove impurities and dried afterwards to maintain the saturated surface dry (SSD) condition.

Table 2: Constituents of RCA used in this study

Constituents of Recycled Aggregates (%)				
Sample	Concrete	Brick	Asphalt	Others
1	78%	6%	5%	11%
2	72%	9%	5%	14%
3	75%	7%	5%	13%
Average	75%	8%	5%	12%

Table 3: Properties of NCA and RCA

Properties Measured	RA	NA	FA
Water Absorption (%)	4.2%	0.8%	3.2%
Uncompacted bulk density (kg/m^3)	1180	1490	-
Compacted bulk density (kg/m^3)	1460	1760	-

2.2 Mix Proportions

In total, seven series of mixes were considered in this study. The first series was control mix contained 100% natural coarse aggregates, while the second, third and fourth mixes were concrete containing 25% RCA that contained 0%, 1% and 2% NS and are termed as R25N0, R25N1 and R25N2, respectively. Similarly, the fifth, sixth and seventh series were concrete containing 50% RCA which contained 0%, 1% and 2% of NS, respectively. The mix proportions of all the mixes are shown in Table 1. The 1% and 2% NS contents used in this study were based on authors recent study on the effect of NS on early age compressive strength of ordinary and high volume fly ash concretes (Shaikh et al., 2014), where 2% NS was found as an optimum content.

2.3 Concrete casting and curing

All concretes were mixed in a pan mixer using constant water to binder ratio of 0.4. As mentioned earlier, the NS was first ultrasonically dispersed in water containing superplasticizer and was added to the mix during mixing along with remaining water. Slump tests were done immediately after mixing the concrete to measure the workability of each mix. At least three specimens were cast and tested in each series. All specimens were water cured until the day before the test date.

The water sorptivity, chloride permeability, and volume of permeable voids (VPV) were measured at 7 and 28 days in each series. The 100ø X 200 mm cylinders were cut into three 50mm thick slices and were used in water sorptivity, chloride permeability and VPV tests. The sorptivity and VPV tests were conducted according to ASTM C1585 (2013) and AS1012.21 (1999), respectively, while the chloride penetration test was conducted according to method proposed by Otsuki et al. (1993).

3 RESULTS AND DISCUSSION:

3.1 Volume of Permeable Voids (VPV)

The volume of permeable voids (VPV) of concrete gives an indication of its durability related to permeability, absorption, etc. The results of VPV are affected by a number of factors including compaction, curing, air entrainment, absorption and physical nature of the aggregate used (AS1012.21, 1999). It can be observed form the VPV results shown in Figure 2 that the percentage of voids in concrete increases as the amount of RCA increases without NS addition and decreases with curing. The inferior properties of RCA are translated into the concrete specimens in which it can be seen from the results that the volume of voids increases by 15% and 37% for concrete containing 25% and 50% RCA, respectively at 28 days, with the results being slightly lower at 13% and 27% for 7 days compared to the control. The increase in VPV of R25N0 and R50N0 concretes compared to the control concrete can be attributed to the higher porosity of RCA than NCA. The higher water absorption of RCA compared to NCA shown in Table 3 is also an indication of higher pores/voids in recycled aggregate concretes.

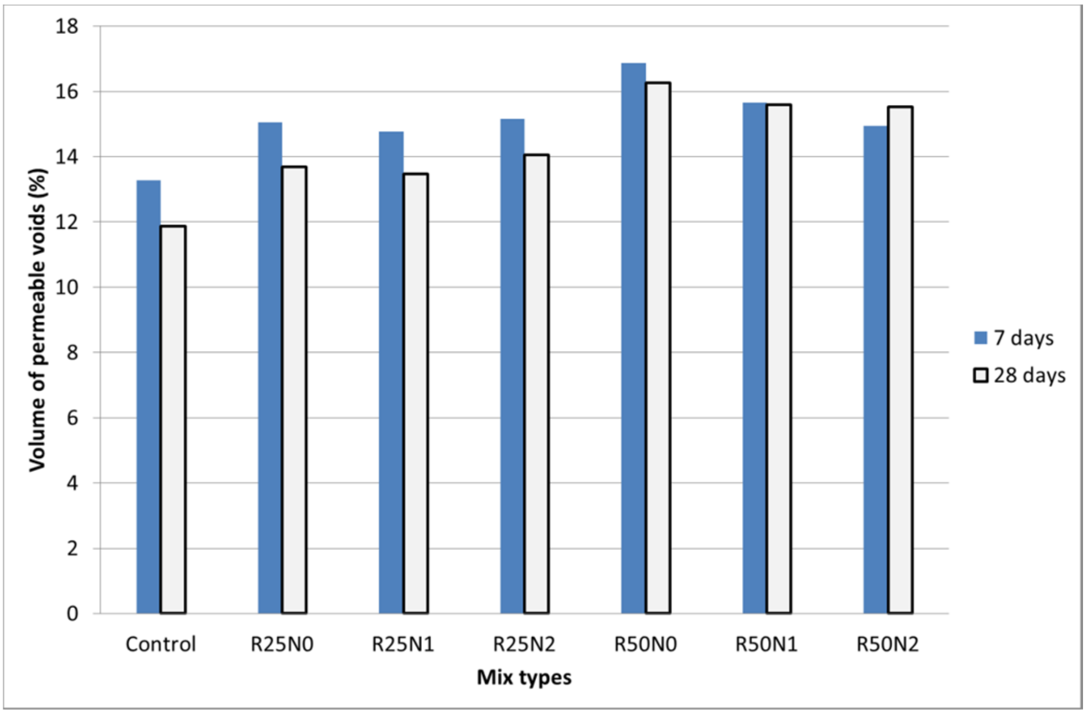

Figure 2: Effects of NS on volume of permeable voids of concretes containing 25% and 50% RCA.

The effect of addition of 1% and 2% NS on VPV of recycled aggregates concretes can also be seen in Figure 2. It can be seen that there is slight reduction in volume of voids of concrete containing 25% RCA due to 1% NS addition. In contrast, the concrete containing 50% RCA, however, exhibited about 7% and 11% reduction in VPV at 7days and 4% reduction in VPV at 28 days due to addition of 1% and 2% NS, respectively. Although it could be said that whilst NS does improve the hydration, and hence the microstructure, this results indicate little improvement and without any further research that looks at the microstructure of the concrete at different replacements, a conclusion cannot be drawn as to why NS did not have a more profound effect on the reduction of VPV.

3.2 Sorptivity

Figure 3 summarises the effect of RCA substitution and NS addition on the sorptivity of concretes measured after 7 and 28 days of curing. It is evident from the figure that the substitution of RCA significantly increases the sorptivity of the concrete, e.g. for R25N0 and R50N0 concretes the sorptivity increased by 33% and 77% at 7 days curing and 44% and 50% at 28 days relative to the control concrete. This increased absorption due to capillary rise is expected and is due to the inferior properties of the RCA e.g. higher water absorption than NCA (refer to Table 3). The higher water absorption of the RCA is primarily linked to the attached mortars on its surface which are very porous and also the high percentage of masonry products (Sagoe-Crentsil et al., 2001). Furthermore given the nature of the RCA manufacturing process, it tends to form cracks and fissures in the aggregate which further contributes to increased sorptivity of concrete.

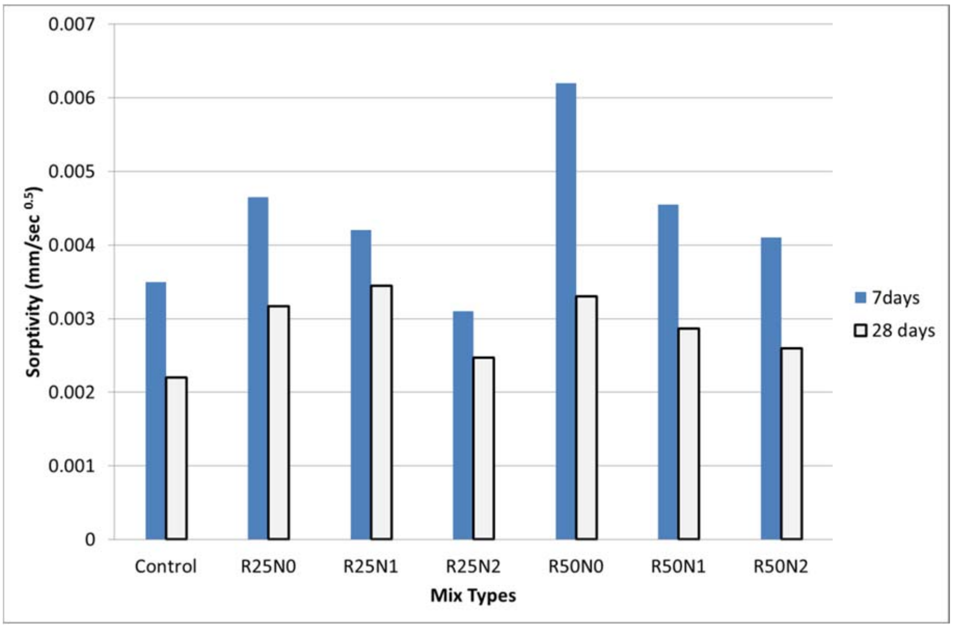

Figure 3: Effects of NS on water sorptivity of concretes containing 25% and 50% RCA.

It can also be seen that the water sorptivity reduced with curing age, due to continual hydration process of cement that reduces capillary spaces and densifies the microstructure which retarded the fluid flow in the concrete. Whilst the test has been conducted on the early ages of the concrete samples, it can be seen that there is a reduction in sorptivity of R25N0 and R50N0 concretes from 7 days curing to 28 days curing, however it is still higher than the control concrete. The reduction of sorption with curing is attributed to the formation of new C-S-H that further densifies the matrix and blocks the interconnected pores within the concrete which thus leads to lower sorption. In contrast, it can be seen that the addition of NS significantly reduces the sorptivity of recycled aggregate concretes specifically at early ages (7 days curing) as can be seen in Figure 3. It can be seen in Figure 3 that the sorptivity is decreased by 10% and 17% for R25N1 and R50N1 concretes, respectively and 33% and 34% for R25N2 and R50N2 concretes, respectively at 7 days. On the other hand, at 28 days it is only 9% higher and 22% lower for R25N1 and R25N2, respectively and 13% and 21% lower for R50N1 and R50N2, respectively. The 25% RCA series in particular displayed promising results for 2% NS addition with it exceeding the control at 7 days due to increased hydration and at 28 days it was only 12% higher relative to the control, and therefore further curing may allow it to exceed the resistance of the control concrete if it is to be investigated.

3.3 Chloride Penetration Depth

It is claimed by some researchers that the chloride ion resistance of concrete depends largely on the porosity and inter-connectivity of the pore system and to a lesser extent on the chemical binding capacity of the cement (Thomas et al., 2013). In Figure 4, it can be seen that upon the partial substitution of RCA, the concrete is more susceptible to the ingress of ions in which for the R25N0 and R50N0 series at 7 days of moist curing, there is an18% and 21% increase in chloride penetration depth and at 28 days, a further increase of 25% and 33% relative to the control sample. This decreased resistance was anticipated, given that RCA had higher water absorption shown in Table 3 and porosity due to the adherence of mortar on the surface which is highly permeable, and also due to the masonry content as can be seen in Table 2.

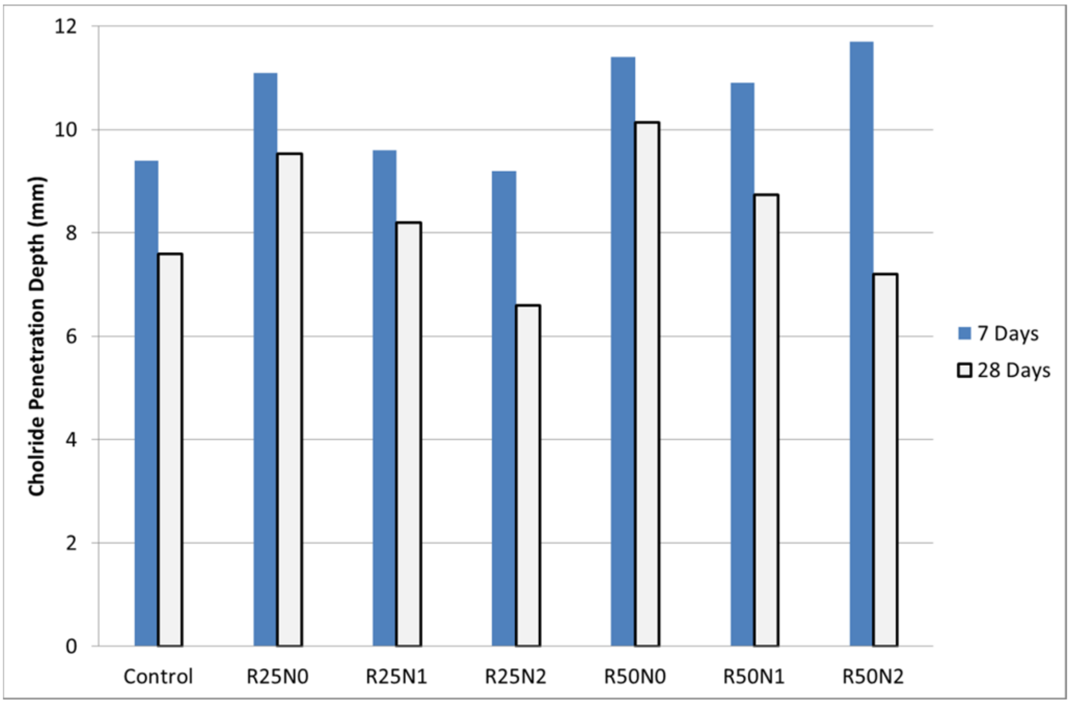

Figure 4: Effects of NS on chloride penetration depth of concretes containing 25% and 50% RCA.

In Figure 4, it can be seen that the curing age has a significant effect on the resistance of all series due to the hydration of cement which further produces C-S-H gels, however the R25N0 and R50N0 concretes exhibited inferior performance as the penetration depths are still significantly larger at both 7 and 28 day curing ages relative to control. It can be seen in Figure 4 that as the amount of NS increased so did the concretes resistance, where for 1% and 2% addition there is a relative decrease of 14% and 31%, respectively for the 25% RCA substitution and 14% and 29%, respectively for the 50% RCA series at 28 day curing.

4. CONCLUSION:

Based on experimental evidence of present study on effect of nano silica on durability properties the following conclusions can be summarized:

- It is observed from VPV results that the addition of NS reduced the volume of permeable voids of recycled aggregate concretes at both 7 and 28 days, with significant reduction at 7 days. When compared to control concrete, no reduction in volume of permeable voids is noticed in both recycled aggregate concretes due to addition of NS.
- In both recycled aggregate concretes the sorptivity is much lower at 28 days than 7 days due to addition of NS and due to long curing. The increased addition of NS decreased the sorptivity of recycled aggregate concretes and at 25% RCA replacement it showed even better resistance than the control concrete and reduced the sorptivity by 11% after 7days moist curing.
- It is suggested from the results that increased addition of NS tends to increase the chloride ion resistance of the concrete given that it acts to promote the hydration and block the capillary spaces within the concrete. The 2% addition of NS decreased the chloride penetration depth of concretes containing 25% and 50% RCA by 31% and 28%, respectively at 28 days and when compared to the control concrete it displayed better resistance and exceeded it by 13% and 5%, respectively at 28 days. In addition, curing age made a substantial difference to the resistance across all series however it was more significant for the series incorporating NS.

5. REFERENCES:

Ahmed, S.F.U. (2013) Mechanical properties of concrete containing construction and demolition wastes and fly ash, *ASCE, Journal of Materials in Civil Engineering.* 25(12): 1864-1870.

Ali, AE, Mohamed, AE and Awad, E. 2012. "Influence of self-healing, mixing method and adding silica fume on mechanical properties of recycled aggregates concrete." *Construction and Building Materials*. 35 (0):421-427.

American society for testing and materials, 2013. Standard test method for measurement of rate of absorption of water by hydraulic cement concretes. ASTM International (ASTM C1585-13).

Ann, K. Y., Moon, H. Y., Kim, Y. B.and Ryou. J. 2008. "Durability of recycled aggregate concrete using pozzolanic materials." *Waste Management*. 28 (6):993-999.

Etxeberria, M., E. Vázquez, A. Marí, and M. Barra. 2007. "Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete." *Cement and Concrete Research* no. 37 (5):735-742.

Ji, T. 2005. "Preliminary study on the water permeability and microstructure of concrete incorporating nano-SiO2." *Cement and Concrete Research*. 35 (10):1943-1947.

Jo, BW, Kim, CH, Tae, GH and Park, JB. 2007. "Characteristics of cement mortar with nano-SiO2 particles." *Construction and Building Materials*. 21 (6):1351-1355.

Kong, D, Du, X., Wei, S., Zhang, H., Yang, Y. and Shah, SP. 2012. "Influence of nano-silica agglomeration on microstructure and properties of the hardened cement-based materials." *Construction and Building Materials*. 37 (0):707-715.

Kou, S. C., and Poon, C.S.. 2012. "Enhancing the durability properties of concrete prepared with coarse recycled aggregate." *Construction and Building Materials*. 35 (0):69-76.

Kou, SC, Poon, CS and Wan, HW. 2012. "Properties of concrete prepared with low-grade recycled aggregates." *Construction and Building Materials*. 36 (0):881-889.

Kwan, W H, Ramli,M., Kam, K.J. and Sulieman, M.Z.. 2012. "Influence of the amount of recycled coarse aggregate in concrete design and durability properties." *Construction and Building Materials*. 26 (1):565-573.

Levy, S M., and Helene, P. 2004. "Durability of recycled aggregates concrete: a safe way to sustainable development." *Cement and Concrete Research*. 34 (11):1975-1980.

Otsuki, N, Nagataki,S and Nakashita, K.. 1993. "Evaluation of the AgNO3 solution spray method for measurement of chloride penetration into hardened cementitious matrix materials." *Construction and Building Materials*. 7 (4):195-201.

Sagoe-Crentsil, K. K., T. Brown, and A. H. Taylor. 2001. "Performance of concrete made with commercially produced coarse recycled concrete aggregate." *Cement and Concrete Research*. 31 (5):707-712.

Shaikh, F.U.A. (2013) A study on the existence of dividing strength in concrete containing recycled coarse aggregate, *ASCE, Journal of Materials in Civil Engineering*, Vol. 26, No. 4: 784-788.

Shaikh, F.U.A., Supit, S. and Sarker, P. (2014) A study on the effect of nano silica on compressive strength of high volume fly ash mortar and concrete, *Materials and design.* Vol.60: 433-442.

Shaikh, FUA, and Nguyen, HL. 2013. "Properties of concrete containing recycled construction and demolition wastes as coarse aggregates." *Journal of Sustainable Cement-Based Materials*. 2 (3-4):204-217.

Standards Australia HB 155:2002. Guide to the use of recycled concrete and masonry materials. Sydney: Standards Australia; 2002.

Standards Australia. 1998. Aggregates and rock for engineering purposes, Part 1: Concrete aggregates. SAI Global (as 2758.1-1998)

Standards Australia. 1999. Methods of testing concrete, Method 21: Determination of water absorption and apparent volume of permeable voids in hardened concrete. SAIGlobal (AS 1012.21-1999).

Supit, S. and Shaikh, F.U.A. (2014) Durability properties of high volume fly ash concrete containing nano silica. *Materials and structures. (*DOI 10.1617/s11527-014-0329-0*)*

Supit, S., Shaikh, F.U.A. and Sarker, P. K. (2013) Effect of Nano Silica and Ultrafine Fly Ash on Compressive Strength of High Volume Fly Ash Mortar. *Applied Mechanics and Materials.* 368-370: 1061-1065.

Thomas, C., Setién, J. , Polanco, J. A. , Alaejos, P. and de Juan, M.S.. 2013. "Durability of recycled aggregate concrete." *Construction and Building Materials*. 40 (0):1054-1065.