Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Study of mechanical and durability aspects of sustainable self compacting concrete made from building demolished concrete wastes

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ABSTRACT

Development of Self Compacting Concrete (SCC) with recycled concrete aggregates (RCA) from demolished and disposed wastes seems a logically viable answers to problems like resource exhaustion and waste management. In this work, three SCC mixes were developed by modification of Nan-Su's method for target strengths of 30, 50 and 70 MPa. Flowability of concrete was ensured to conform to EFNARC specifications through various fresh property tests. Compressive strength tests were conducted to include assessment of variation in curing period for durations of 28, 56 and 90days. Durability properties like resistance to H_2SO_4, capillary water sorption effects of use of RCA were studied. Observations indicated that better results will be obtained if processed RCA are used. RCA concrete couldn't attain compressive strength as that of Natural aggregate (NCA) concrete and also the effect of acid and capillary water sorption were amplified in case of greater replacements of RCA.

Keywords. Recycled aggregate, SCC, durability, age of curing, capillary water sorption, acid resistance

INTRODUCTION

Modern day infrastructural needs demanded a versatile concrete which was highly workable and as durable as possible. Development of SCC answered this call and has proven its significance ever since its inception. Demolition waste from structures is common from developmental activity, improper construction or any natural cause. The practice of disposing these wastes as landfills demanded a change because of its environmental and economic implications. The aggregate used in preparation of old concrete was considered inert and is possibly an exploitable resource. These concrete wastes account to about 50% of total C&D wastes in North America and European Union. Hence exploiting the inert aggregate part of this concrete waste seems a decent point from where the search for sustainable concrete can be initiated without problem.

Though this point was observed long time back, its integration with SCC and its durability were not properly exploited probably because of its high workability requirements. Pioneer work in use of RCA as structural material was in normal concrete and not SCC (Limbachiya, 2004). Several prospects of use of RCA in certain typically different requirements of concrete were also exploited (Vardaka, 2010). Previous work in this field was orchestrated by several others (Tavakoli and Soroushian, 1996; Topcu and Guncan, 1995). A decrease in compressive strength was observed in all concretes by using old aggregates and also the mechanical properties decreased with increase in proportion on recycled aggregate (Topcu and Guncan, 1995). It was also discovered that the extent and method of recycling influenced the properties of consequent concrete (Montgomery, 1998). Influence of using industrial by products like fly ash and silicafume in concrete were also well understood (Shi Cong Kou et al, 2007). Attempts and thus significant progress was also made in improvement of quality of RCA (Sri Ravindrarajah, 1998).

Concrete generally may be exposed to several different conditions like extremely acidic, highly moist, high amounts of carbon di oxide and several others. Several studies indicated distinctly the effect of several factors on the behaviour in acid environment (Bassouni, 2007; H Khelafi, 2010). However these studies did not include the RCA parameter in them but laid a foundation to such thought. Khatib et al (2011) studied the influence of using fly ash in concrete on water absorption ability.

MATERIALS AND MIX DESIGN

Materials. Cement (3.11g/cm^3 density conforming to IS 12269)(Table 2), Fly ash (Class F**,** density 2.05g/cm^3) and silica fume (conforming to IS 15388) were the binders used. Fine aggregate or sand used was of Fineness modulus = 2.6 and conforms to IS 383. Coarse aggregates, both natural and recycled were used at a fineness modulus of 7.1. Workability enhancing Sulphonated Napthalene Formaldehyde admixture conforming to ASTM C494 (A&F) with a specific gravity 1.223 was used as water reducing admixture.

RCA used in this work were obtained from 40year old concrete tank of M20 grade, jaw crushed and unprocessed, mainly because of concerns regarding energy needed and also its associated environmental and economic concerns. Influence of variation in processing of aggregates was not studied even though they affect certain properties (Winkler and Mueller, 1998).The studies were directed to understand the effect of worst possible case of use of RCA. Certain properties of recycled aggregate were tested in order to check their compatibility for use in concrete as per (RILEM TC 121 and IS 383). The variations amongst the various proportions of recycled aggregate are mentioned in Table 1. Chemical compliance with provisions was also ensured.

Table 1: Properties of RCA

Property	100% NCA (Mix /1)	25% RCA (Mix /2)	50% RCA (Mix /3)	100% RCA (Mix /4)
Bulk density	1.46	1.44	1.39	1.28
Specific gravity	2.78	2.72	2.68	2.55

Angularity Index	10.31	11.35	12.09	13.99
Water absorption	1.00	2.10	3.52	5.68
Crushing Strength	22.77	23.00	24.21	28.16

Table 2: Important physical and chemical properties of cement

Property	Value	Limits (as per IS 12269)
Fineness	320 m^2/Kg	Min 225 m^2/Kg
Autoclave expansion	0.10%	Max 0.80 %
Total loss on ignition (% by mass)	1.3%	4.0 %
Total chloride (% by mass)	0.011%	Max 0.1%

Mix Design. The mix designs for SCC were developed based on literature (Nan Su, 2001), however the aggregate percentages were decided from minimum void ratio testing (H. Bouwers, 2005). The mixes were designed for target strengths of Mix-A (30Mpa), Mix-B (50Mpa), Mix-C (70Mpa).Because of low strength and higher drying shrinkage due to recycled aggregates, 10% Silicafume replacement is sought in case of Mix-C to improve the results(Faiz Mirza,2010). Several trials were conducted to ensure that mixes met all EFNARC requirements (EFNARC, 2002). The compliance of fresh properties of final mixes to the specifications are given in Table 3. The final mix design for all three target strengths are given in Table 4.

Table 3: Fresh properties of all mixes

Mix	Slump flow (mm)	T_{50} (s)	V time (s)	V_5 time (s)	U box	J ring
30MPa	680	1.58	8.28	9.26	24	1
50MPa	720	4	8.4	10	25.6	3
70MPa	700	3.4	8.0	10.6	22	4
EFNARC	650-800	2-5	6-12	0 - +3	0-30	0-10

Table 4: Mix designs for 3 targets

Mix	Cement	Fly ash	Silica fume	Sand	Coarse aggregate	Water	SP (% powder content)

Mix-A	276	150	---	961	808	200	1.37%
Mix-B	412	138	---	913	781*	193	1.67%
Mix-C	517.5	86	57.5	860	786*	185	2.41%

**Maximum size of aggregates varied

Maximum aggregate size in Mix B, C are reduced to 16mm and 12.5mm respectively to obtain maximum packing as per Compressive Packing Model (Rathish Kumar, 2012)

EXPERIMENTAL PROGRAM

Concrete cube specimens (150x150x150 mm) were cast with four variations in percentage replacements in RCA and three target strengths. Natural aggregate (A/1, B/1, C/1), 25% RCA (A/2, B/2, C/2), 50% RCA (A/3, B/3, C/3) and 100% RCA (A/4, B/4, C/4). Concrete was prepared in a pan mixer and the cast specimens were air cured for 24hrs after which cubes were demolded and placed for water curing in 27^0C for different curing periods. The cubes after removal from curing after desired period were tested for compressive strength after their drying. Cubes were completely immersed after 28days of curing, in acid solutions prepared with 5% H_2SO_4 for desired periods of time and were periodically observed for mass and dimensional changes. Capillary water sorption was studied by ensuring 5 - 10mm of cube bottom in contact with water and water-proofing by glass and paraffin on all other edges & side faces.

RESULTS AND DISCUSSIONS

Compressive Strength. Preliminary investigation (Figure1 & Tables 5, 6, 7) concluded that RCA are slightly inferior in delivering compressive strength when compared to NCA and this inability is increasing with the increase in strength. Though the compressive strength finally obtained was slightly less than that obtained by NCA, it was well above the target strength aimed at and hence it is safe to say that RCA can be used in structural concrete from a compressive strength point of view but caution is advised for higher grade applications.

Inability to attain higher strength in case of RCA may be attributed to their use in raw, unprocessed form. Examination of the failure cross section showed that the failure occurred through the mortar aggregate transition phase of the RCA. Use of RCA in unprocessed form resulted in a slightly weaker zone, followed during failure. Thereby we could predict that use of RCA in a processed and cleaned form will result in better compressive strength.

Table 5: Compressive strengths of 30MPa

Mix type	28day strength	% variation wrt A/1	56day strength	% variation wrt A/1	90 day strength	% variation wrt A/1

A/1	36.03±3.2	0	46.53±2.0	0	49.74±5.2	0
A/2	35.27±2.9	2.1%	44.98±2.7	3.3%	48.10±4.1	3.2%
A/3	33.73±3.1	6.3%	43.95±4.9	5.5%	46.92±3.7	5.6%
A/4	33.22±1.4	7.7%	42.93±3.4	7.7%	46.10±2.9	7.3%

Table 6: Compressive strengths of Mix - B

Mix type	28day strength	% variation	56day strength	% variation	90day strength	% variation
B/1	55.34±6.2	0	64.34±6.0	0	66.21±5.8	0
B/2	53.15±5.9	3.9%	62.87±5.7	2.2%	64.56±5.2	2.5%
B/3	51.79±6.3	6.4%	59.21±6.1	7.9%	61.18±6.1	7.5%
B/4	50.33±6.7	9.0%	58.9±6.5	8.4%	61.02±6.3	7.8%

Fly ash is held responsible for the late gain in strength, though it was not considered to give any strength as per mix design (filler), its significance is predominant in terms of late gain strength**.** Strength variation seems to reduce with the age of curing, suggesting that RCA concrete develops more late strength probably because RCA acting as water reservoirs providing more water at later stages for fly ash reaction, when compared to NCA.

Observations in case of Mix- C (70Mpa concrete), show almost same compressive strength for all replacements contrary to observations (Fakitsas et.al, 2012). This could be because of use of unprocessed RCA. Invariance in this case is understood as a consequence of silica fume’s micro filler effect making all proportions behave similarly in terms of strength.

Table 7: Compressive strengths of Mix - C

Mix type	28day strength	% variation	56day strength	% variation	90day strength	% variation
C/1	72.69	0	77.58	0	83.01	0
C/2	72.21	0.66%	76.54	1.3%	82.82	0.22%

C/3	71.12	2.1%	75.78	2.3%	82.32	0.83%
C/4	70.75	2.6%	75.11	3.1%	81.84	1.41%

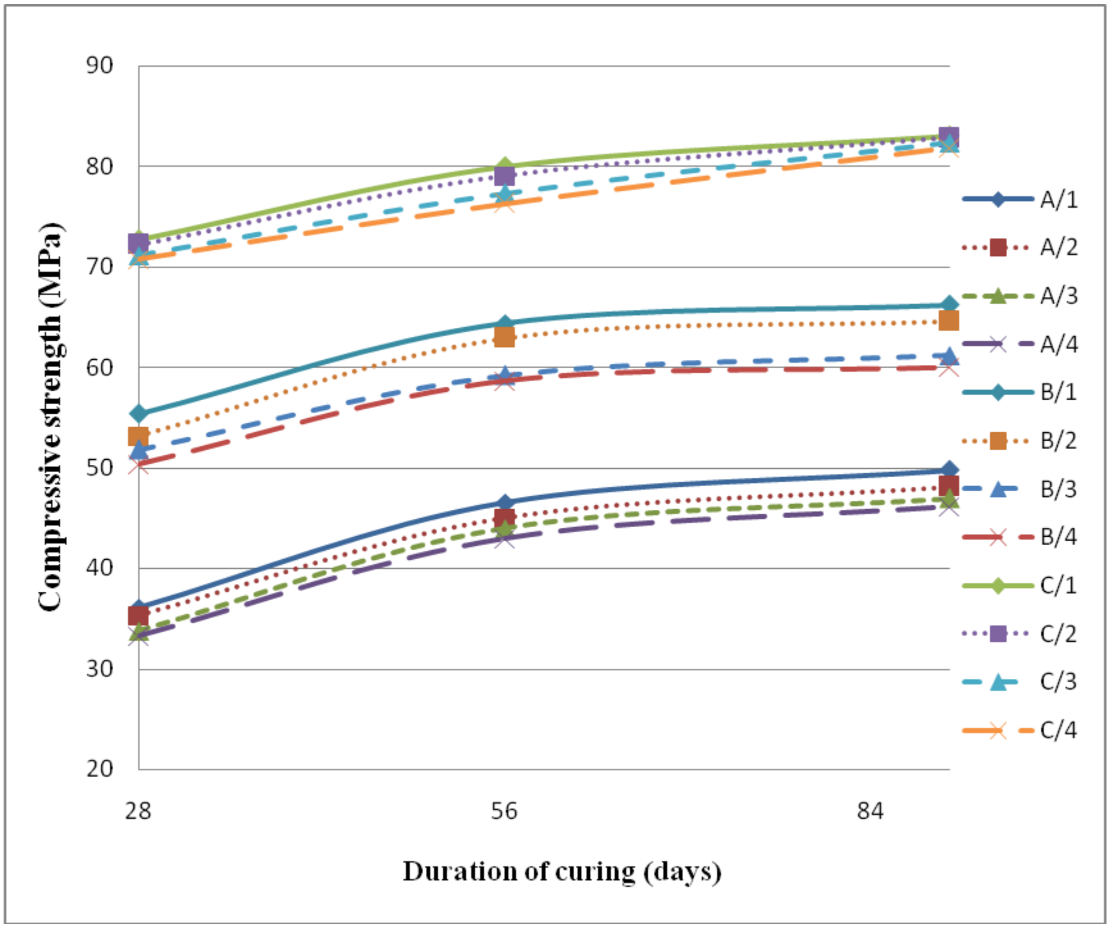

Figure 1:Strength development with age of curing of RCA - SCC for different grades

We observed an increase in strength after 28 days and also its increase with grade, in proportion to the added amount of fly ash. Incase of 70MPa concrete, increase in RCA performance is due to silica fume and its consequent densification resulting in stronger internal structure and mitigating the effects of using RCA. We can thus conclude that use of mineral admixtures not only limited cement content but also assisted in improved performance of RCA.

Acid resistance. The cubes immersed in 5% H_2SO_4 solution were periodically tested for their weight loss and dimensions. Results are depicted in Figures 2 and 3.

This particular method of testing for sulphuric acid resistance is theoretically, known for interference from associated sulphate attack. It is a known thing that sulphate attack causes significant expansion during deterioration, periodic measurements of concrete specimen dimensions suggested that there was almost no scope for deterioration due to sulphate attack and since the objective was study in acid attack, sulphate attack was left unattended.

It was observed that exposure to acid resulted in leaching of concrete layer by layer and also significant de-bonding effect could be observed. Primary conclusion we could draw from these observations is that natural aggregate, though in some cases yielded more mass loss, has a significantly lower rate when compared to that of replacement of RCA. Mass loss is increasing with cement content and hence, grade as suggested previously (Bassouni, 2007).

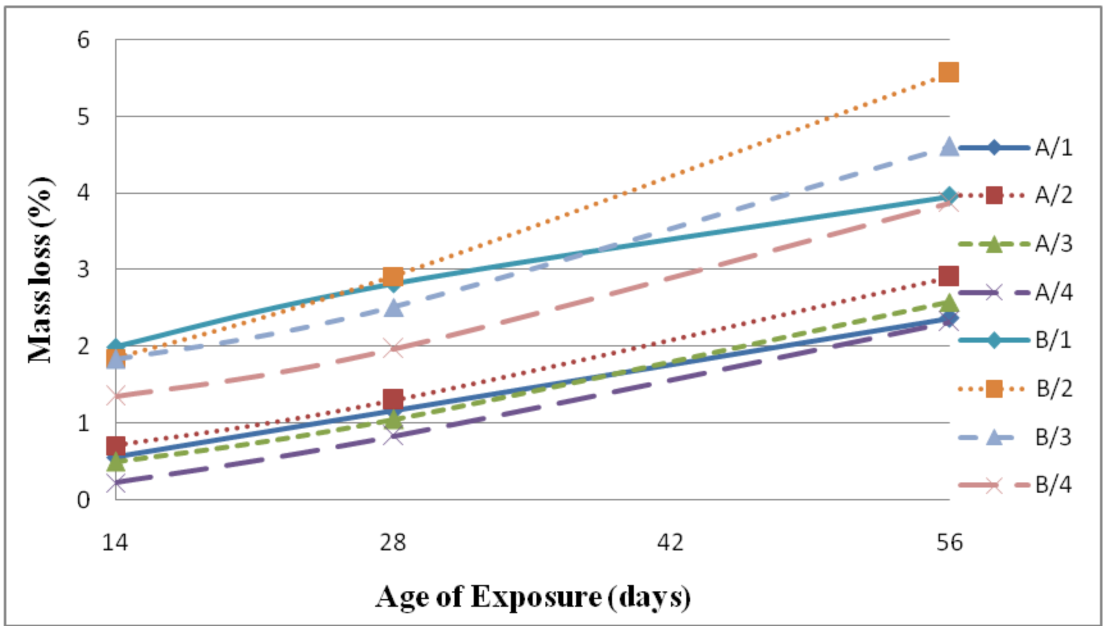

Figure 2: Performance of RCA-SCC in acid environment for 30MPa and 50MPa mixes.

In case of Mix – C (70MPa) we actually expected slightly lower mass loss than in previous cases because of addition of Silica Fume which densified the concrete, making it slightly less vulnerable (Daczko, 1997). Our expectation could not be observed probably because, concentrations used by Daczko were lower than those used in this study, suggesting that atleast 2-5 % concentration of acid is required for decomposition of CH and CSH in concrete.

Significant rise in mass rate of RCA concrete can be ascertained to effect of RCA ITZ (inter transition zone), from where it is believed that leaching of layers started. Higher the replacement, more dominant the weaker ITZ leading to higher mass loss rates. Processed RCA might have performed better in this context

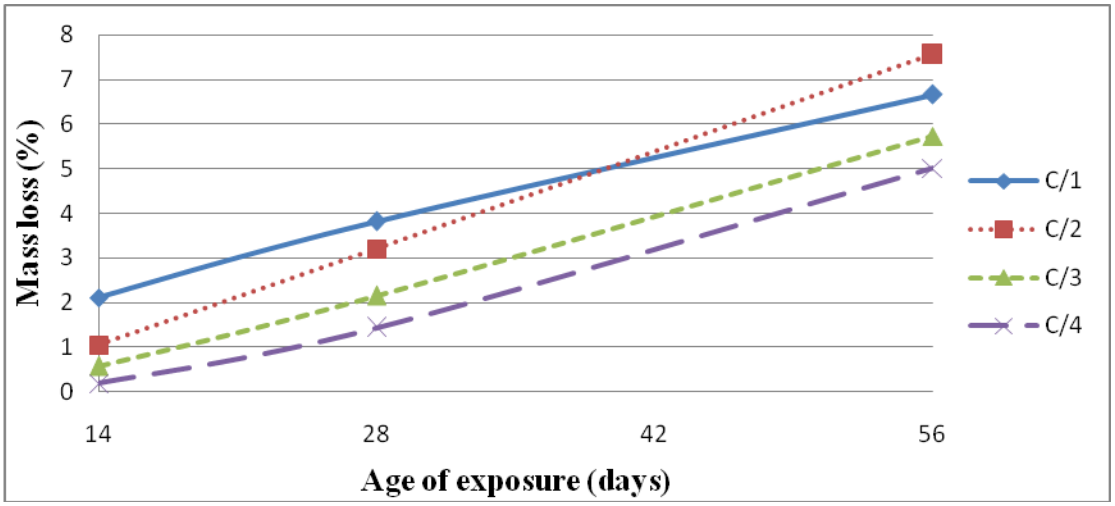

Figure 3: Mass loss in 70MPa specimens due to acid exposure.

The amount of acid attack also depends on water movement on surface of concrete, in this case stagnant water was used and hence the values observed are relatively lower.

Water Sorption. The results of capillary sorption testing can be seen in Figures 4, 5, and 6.

Sorptivity was not given much importance because it seemed a surface characteristic indicator given the time of observation and so the process was continued for longer durations expecting an idea of internal structure which could be related to durability in the long run.

Mass gain reduced with grade, suggesting an overall improvement in internal structure and increased with RCA suggesting that higher porosity is evident with higher replacements. Since mass gain was believed to indicate durability, a 10 - 15% lenience in performance, comparing against natural aggregate, we ended up at a safe RCA replacement of 20 -25%.

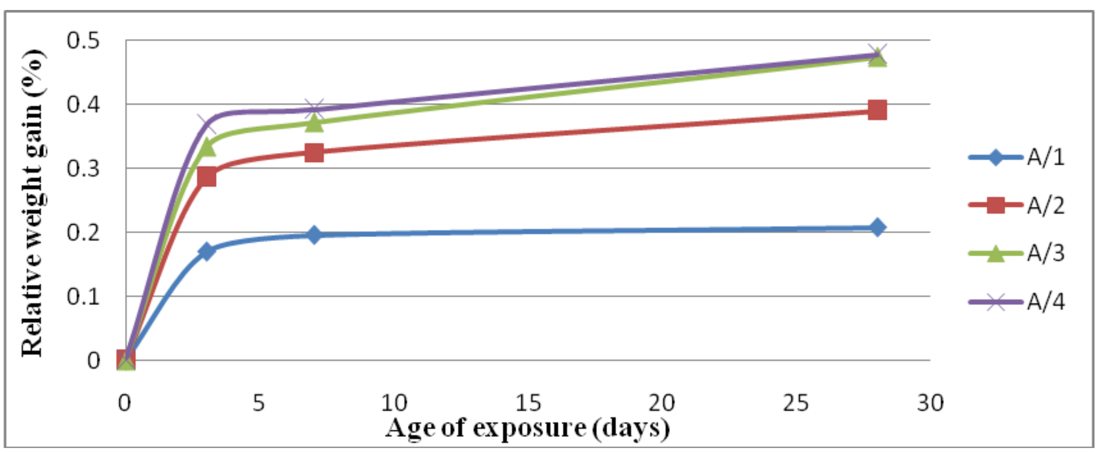

Figure 4: Weight gain due to capillary water sorption for Mix-A

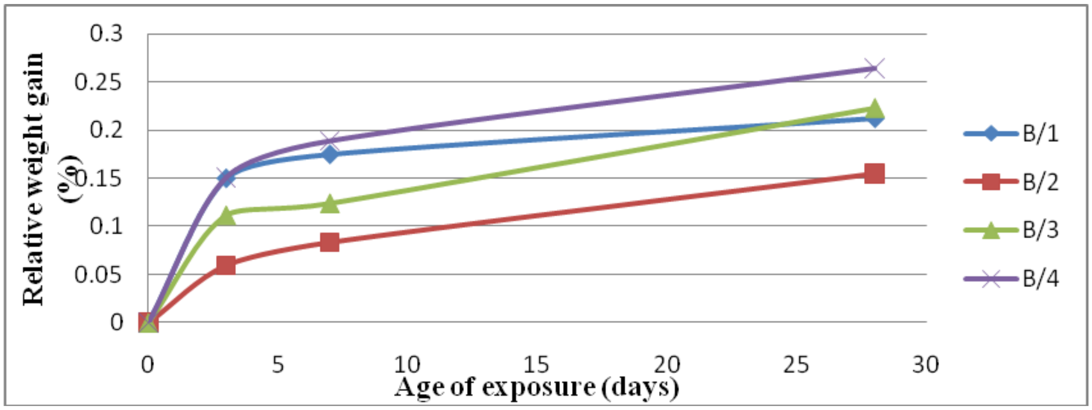

Figure 5: Weight gain due to capillary water sorption for Mix-B

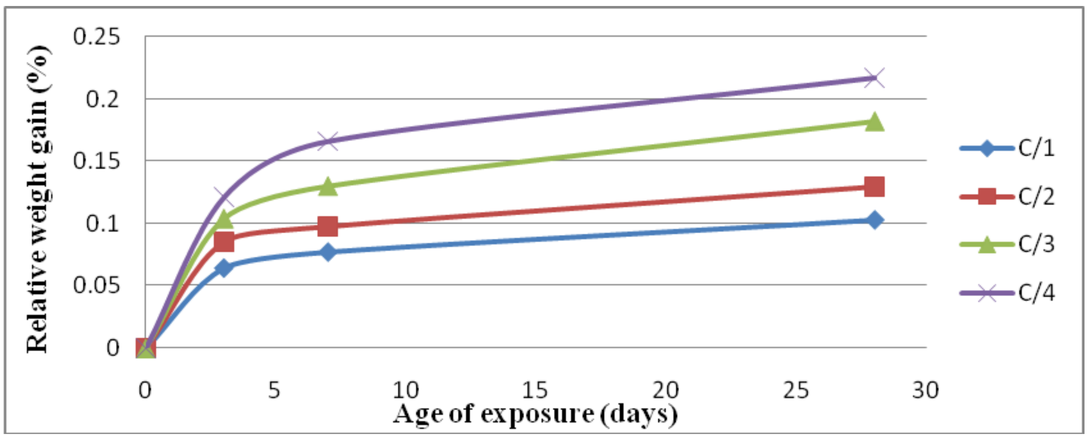

Figure 6: Weight gain due to capillary water sorption for Mix-C

CONCLUSIONS

- RCA concrete failed to attain strengths same as that of natural concrete, but the inability is less than 10% but increasing with the grade of concrete.
- RCA concrete has higher strength gain when compared to natural concrete, this was partially attributed to the use of mineral admixtures like fly ash and silica fume, hence RCA concretes are better when coupled with mineral admixtures,
- Processing of RCA is beneficial since the performance is being improved but a balance is to be attained between extent of processing and required properties because of energy and cost of processing.
- Deterioration in acid environment increased with grade and RCA content, mostly because of the weak ITZ and also action due to silica fume depends on acid concentration.

- Higher RCA content showed greater porosity hence it should be ideally limited to 20-25% for durable performance, allowing a 10-15% lenience from NCA concrete behaviour.

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