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Investigation of some Technical Properties of Recycled Materials

By Rajesh Kumar Jain
Sainath University, India

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Keywords: RA, NA, PFA, SCC, unit weight, workability, slump, strengths.

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INVESTIGATIONOFSOMETECHNICALPROPERTIESOFRECYCLEDMATERIALS

Strictly as per the compliance and regulations of:

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I. Introduction

Infrastructure scenario of India showed that total investment has been double in 2011-12 vis-à-vis 2007-08,projected to cross 500,000Cr.In 2009-10, Govt. to spend Rs. 60000Cr only for up gradation of roads and private sector investment in roads to cross 35% by 2011-12 , while India has second largest road network (3.3 million km) in world and the Highway Network density is 0.66 km/sq.km of land .It accounts for 90% passenger traffic and 65% of total fright (~960 million tons/km-yr).The Eleventh Five Year Plan has a special focus on Rural Infrastructure Development[1].

The global production of cement is estimated at 2.7 billion tonnes in 2007 and should reach 3.4 billion tonnes and 3.5 billion tonnes by 2010 and 2012 respectively; demand is expected to grow by 4.7% annually[2,3]. Greater dependency on fossil fuel such as coal for electricity generation due to the current global economical crisis could result in more production of fly ash. The need to manage construction and demolition waste (CDW) has led to environment friendly actions that promote the reuse and recycling of this type of waste and other forms of waste valorization.

Recycled aggregates are those resulting from the processing of materials previously used in construction [4]. However, despite the enhanced quality of the recycled aggregates, the uptake of this alternative is still in fact too low[5,4]). The level of impurities is usually medium to high and can significantly affect the strength and performance when recycled in concrete. The limitation and provisions set in standards such as BS 8500-2: 2002 [6,7] split the available recycled material into four main categories.

The construction industry uses more materials by weight than any other industry[8]. A number of recycled materials are known to provide performance benefits, e.g. ground granulated blast furnace slag (GGBS) and pulverized fuel ash (PFA) as recycled cement replacement materials. The world production was 0.5×10^{12} t in 1989[9], it reached 0.6×10^{9} t in 2000[10]. In particular PFA improves workability, hinders segregation and alleviates bleeding, lowers heat of hydration and the risk of thermal cracks. Increases long-term strength, reduces permeability ,enhances the concrete stability to resist chemical attack and reduces harmful aggregate-silica reaction. Extends setting time and provides longer time for handling and casting of concrete. Due to these merits, PFA is increasingly considered in all sectors of the concrete industry. Red granite dust (RGD) is the fine powder produced from the rock faces when rocks are cut and crushed to produce coarse aggregate. A number of research papers on recycled self compacting concrete are there [11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29].

II. Objectives

For more than one reason, the concrete community need to appreciate that projects should go in harmony with the concept of sustainable development. The use of recycled aggregates in construction, to the maximum possible limit. The use of PFA to produce natural aggregate concrete (NAC), particularly high strength concrete (HSC). To examine

Author: Department of Civil Engineering, Sainath University, Ranchi, India. e-mail: rajmeerutcity@gmail.com

the potential of producing RAC concretes made with SP, PFA, and RGD in both conventional and self-compacting concrete (SCC).

III. Material and Method

Kiyoshi (2007)[30] suggested a new production method for recycling aggregate for concrete. BS 8500-2: 2002[6] provides a basis for the use of RA in concrete. To obtain good quality materials from recycling sites, many researchers [31,32,33,34] suggested that contaminants should be removed before crushing. As per BS 8500-2:2002[6], limits were imposed on recycled aggregate composition. Recycled washed aggregate of 20 mm size that required no extra processing will be used as it was supplied from the recycling plant. This aggregate had been processed (crushed and screened) at Recycling Plant. The impurities were not removed from the RA so that their effects on the characteristics of the produced RAC are included; this is to simulate the case of real conditions when RA is used to make RAC in site.

RA was obtained by processing natural concrete produced in the laboratory by jaw crusher and used to replace the crushed black basalt stone in RAC mixes. RA replaced NA at levels of 25, 50, 75 and 100%. Natural concrete fine aggregate of medium grading was used throughout all the experimental work. PFA that complies with BS EN 450- Parts 1 and 2: 2005 [35,36] will be used as a mineral admixture. Crushed granite NA of 20 mm size which was proven to produce excellent NAC, and will be applied in this investigation. Granite is an extremely durable aggregate with high strength and superior quality. NAC will be used as control mixes. A general rule for the quality of water in concrete is that if it is fit for human consumption it can be used for concrete.

IV. Material Testing

a) *Testing of Aggregates*

To obtain representative samples, aggregates were riffled in compliance with BS 812: Part 102: 1989 "Method of Sampling", the sample is split into two equal portions to decrease the size to a practical amount while ensuring the sample is representative. The selected aggregate samples were then tested for grading, impact, relative density, water absorption, and porosity. The estimation of impurities in the recycled aggregate will also be given. The description of each test, the apparatus used, and the procedure are according to standards. For instance BS 882 for particle size distribution sieve analyses, BS 812 Part 2[37] for particle density and water absorption, BS 812 Part 112[38] for aggregate impact value, etc.

b) *Grading of coarse aggregates*

Sieve analysis was carried out on all coarse and fine concrete aggregates before their use in the experimental work. The sieve analysis is used to find the amount of different size aggregate in a particular sample; it is carried out by putting the sample through a series of sieves that get progressively smaller. For control purposes all samples of aggregates were air dried for equal periods of time before testing. Suitable stacks of sieves were used for each analysis in accordance with BS 812: Part 103: 1989[39] and BS 410: 1986[40].

c) *Grading of fine aggregates*

Natural fine concrete aggregate was used throughout the investigation. The grading limits according to BS 882-1983[41] for fine aggregates.

d) *Aggregate impact value*

The aggregate impact value (AIV) is used to establish the material's ability to resist impact and assess the extent of particle crushing thereafter. The impact value is calculated by recording the fractions passing and retained in a 2.36 mm sieve after the material has received 15 blows from a standard weight. This is expressed as a percentage of the total weight. This test is carried out to measure the resistance of a particular aggregate to sudden shock or impact. AIV in accordance with BS 812-112:1990 [38] were determined in a dry condition for all aggregates.

e) *Unit weight of aggregates*

Aggregates were tested under saturated surface dry conditions (SSD) in accordance with BS 812: Part 2: 1995 [37] to measure the unit weight.

f) *Testing cement, PFA, and RGD*

As cement, PFA, and RGD powder are very fine materials having low solubility in water at 20°C, wet sieve analysis is usually carried out for their gradation. Representative samples dried in an oven at 115 ± 5°C were used to undertake wet sieve analysis to BS 1377:1990[42]. The Vicat method has been based on shearing cement paste with a needle and on the idea that stiffening during the set induces a gradual increase in resistance to shearing. Although the Vicat test's application was generalised in the 19th century, the test remains today the most widely used test by cement manufacturers and is the subject of multiple standards (BS EN 196: Part 3: 2005; NF EN 196-3; ASTM C191-93; AASHTO T 131).[43,44,45,46,47].Slump and Vebe time were measured every 30 minutes over a period of 90 minutes in accordance with BS EN 12350-1: 2000 and BS EN 12350-2: 2000.[48,49] Spreading diameter of the initial slumps was also measured.

g) *Water cement ratio*

It is well known that the major factor controlling the strength of concrete is the water-cement ratio (w/c) or more precisely water to binder ratio (w/b). For a concrete to pass as a self-compacting concrete, it must satisfy certain requirements set out in BS EN 206-9[50]: Additional Rules for self-compacting concrete (SCC); testing methods and standards are covered in BS EN 12359[51].

V. Result and Discussion

Recycled aggregates are composed of the original aggregates and the adhered mortar. It is well known that physical properties of recycled aggregates are very much dependent on the type and quality of the adhered mortar. The crushing procedure of the RA and the size of recycled concrete masses have an influence on the amount of adhered mortar[52]. The adhered mortar is a porous material; its porosity depends upon the w/c ratio of the recycled concrete employed[53]. Cracks in the adhered mortar due to crushing can be considered as a source of weakness[54]. However, with a high strength matrix, cracks can be filled with new mortar to appreciably increase the matrix-aggregate bond.

Table 1 : Sieve analysis of NA and RA coarse aggregates

Sieve size (mm)	Percentage by mass passing BS sieves for nominal sizes		Limits for single-sized aggregate
	N A	R A	
38.0	100	100	100
21.1	90.6	89.2	87-100
15.3	35	41.9	-
11.2	7.2	5.1	0-25
5.8	0	0	0-5
2.36	0	0	-

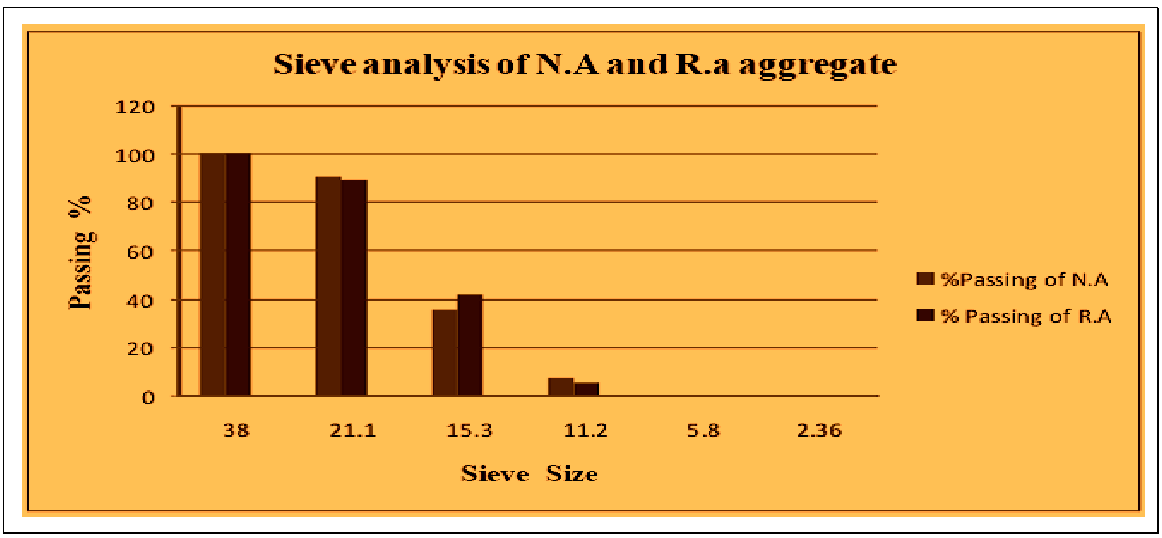

Figure 1 : Sieve analysis of N.A and R.A Aggregate

The data presented in Tables 1 & Figure 1, compared with grading limits for coarse aggregate from BS 882-1983[55] indicate that the tested NA and RA had sieve analysis gradings which placed them within the limits for 20 mm aggregates. The same aggregate with almost the same grading will be used; it is well known that the use of aggregates with different grades could have significant influence on workability and strength of concrete, even when the same type of aggregate is used. According to Mehta & Aïtcin (1990)[56] the small particles are less reactive than larger one, but when dispersed in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products of the cementitious paste.

Table 2 : Sieve analysis of fine aggregate

Sieve size	Mass Retained (g)	Mass passing (g)	Retained (%)	Cumulative passing (%)	% Passing (Overall limits from BS 882)
10 mm	0	571.11	0	100	100
5 mm	12.84	546.30	4	97	89-100
2.36 mm	90.83	460.01	18	83	60-100

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1.18 mm	83.44	363.42	15	68	30-100
600 µm	66.77	289.05	14	55	15-100
300 µm	95.94	196.11	19	39	5-70
150 µm	88.04	106.70	18	22	0-15
Loss (g)	0.71				
Loss (%)	0.12				

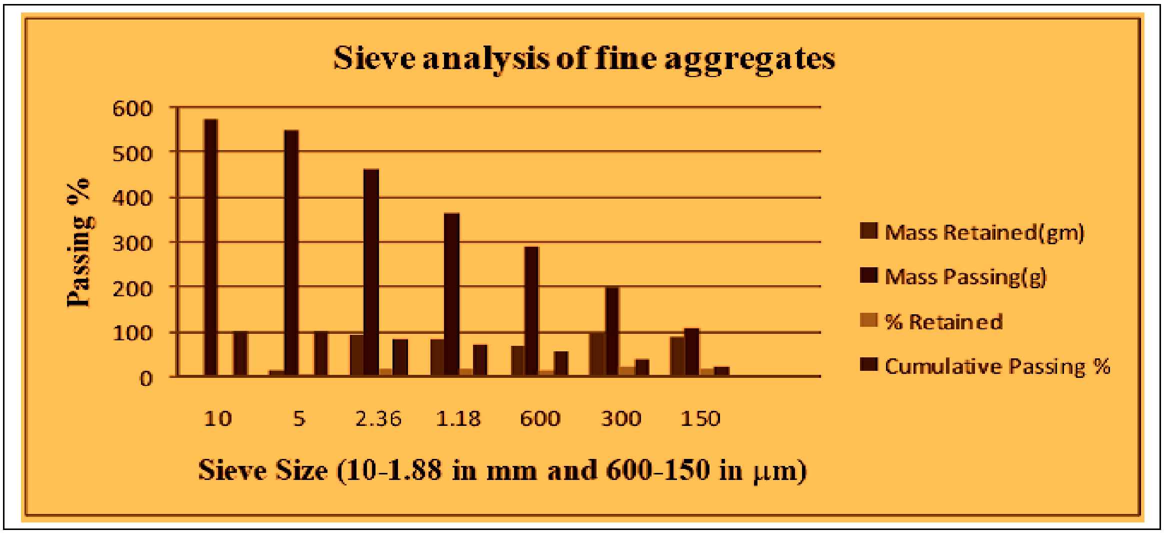

Figure 2 : Sieve analysis of fine aggregates

Table 3 : Impact value test for NA and RA

Type of aggregate	NA	RA
Mass of steel cup	2615 g	2592.4 g
Mass of cup and aggregate	3273.42 g	3412.7 g
Mass of aggregate (Mass A)	638.32 g	611.1 g
Mass passing 2.36 mm (Mass B)	28.13 g	67.5g
Mass retained	618.07 g	549.14 g
AIV= (B/A) × 100	4.32%	13.3%

The AIV is determined as the percentage of the fraction of fines due to impact to the total aggregate; that is (B/A) × 100.

The average impact value of four specimens showed (Table-3) that the AIVs were 4.5 and 12% for NA and RA respectively. Based on the categories given in BS 812: Part 112: 1990[38], the aggregates fall within the suitability limits for concrete which can be used for heavy duty flooring and pavement wearing surfaces. However, good AIV is not the only parameter that guarantees good quality concrete. Table 3 shows that the RA is weaker than NA but this was expected, mainly due to the presence of mortar that adhered to RA particles which resulted in an increased amount of fines obtained under impact. A lower percentage of AIV indicates tougher and stronger aggregates. Results showed that concrete strengths were influenced by aggregate type. Although comparable, the cube strength of all RAC concerts were below similar NAC at all ages, this may be attributed to the superior quality of natural granite aggregate used to create NAC concrete mixes, and to the presence of deleterious materials in RA. For relatively rich RAC concrete mixes; *i.e.* having higher cement content, strength is evidently controlled by the RA, and RAC did not benefit much from the improved strength of the paste matrix; perhaps the strength of aggregate is limiting the ultimate strength.

Table 4 : Relative density of coarse NA

Property	Relative density (RD)		
	Sample 1	Sample 2	Sample 3
Weight in air (g)	2024.2	2114.6	2064.5
Weight in water(g)	1275.5	1320.7	1292.2
Volume (cm^3)	748.7	793.9	772.3
Average RD	2.704	2.664	2.673

Density of water 1g/cm3

Average RD of NA = 2.91.

Table 5 : Relative density of coarse RA

Property	Relative density (RD)		
	Sample 1	Sample 2	Sample 3
Weight in air (g)	2342.3	2293.7	2371.2
Weight in water(g)	1390.4	1401.2	1399.7
Volume (cm3)	898.6	869.7	896.8
Average RD	2.763	2.865	2.714

Average RD of RA = 2.73.

Results showed (Table 4 & 5) that the average unit weights (or densities) were 25.5 kN/m^3 (2600 kg/m^3) and 24.5 kN/m^3 (2500 kg/m^3) for NA and RA respectively. As these densities are > 2000 kg/m^3, NA and RA were classed as normal weight aggregates. The relative density of a material is the ratio of its unit weight to that of water and it has a major influence on the density of the finished concrete. Most rock types have relative densities within a limited range of approximately 2.55 - 2.75, and therefore all produce concretes with similar densities, normally in the range of 2250 - 2450 kg/m^3, depending on the mix proportions [57]. The relative density of fine aggregate and PFA were 2.6 and 2.25 respectively, therefore, the actual amounts of fine aggregate used were 525 kg/m^3 and for PFA 175 × 2.25/2.6=151 kg/m^3. Relative density is used to determine the equivalent weight of a material to a certain volume; for instance if a coarse aggregate of relative density 2.7 represents 60% by volume of concrete, the equivalent weight should be 2.7 × 60 × 9.81 = 1589 kg/m^3 (W = mg = ρvg), where g = 9.81 m/s^2 is the acceleration due to gravity. Turcotte (1993)[58] explores the fractal relationship, or its possibility, between particle size and specific gravity. The rounded average specific gravities of the tested aggregates were 2.7 for NA and 2.5 for RA .Results showed that RA density is slightly lower than that of NA, probably because of the presence of impurities and old cement paste. However, when a material is partially substituted for another in a mix, the replacement by weight could result in a greater volume of the material in the mix if the difference between their specific gravities is large; therefore if the density of RA is much lower than NA, mixes should be proportioned to take this difference into account. In this study no partial substitution will be examined and 100% RA will be used. Water absorption values were 6-7% by mass when RA was used at 20% by mass of NA, and 9% when used at 100% of NA (Levy 2004). Water absorptions of 5-10% can generally be found for recycled aggregates, however, relatively low absorption values were found for coarse recycled aggregates[59]. Water absorption in RA ranges from 3-12% for coarse and fine fractions; this value is much higher than that of the natural aggregate for which the absorption is about 0.5-1.0% [60].

a) Recycled self-compacting concrete

If self-compacting recycled aggregate concrete (RAC-SCC) is shown to achieve similar properties as its counterpart natural aggregate concrete (NAC-SCC) then it can be a viable alternative for the concrete industry.

b) Recycled SCC Production

A standard concrete mix, which will be considered as a reference mix, was designed to achieve 50 N/mm^2 at 28 days with a high slump of 60-180 mm and Vebe time of 0 - 3 s in accordance with the Building Research Establishment mix design method (BRE 1992)[61]. Mix proportions are shown in Table 6 and 7.

Table 6 : Mix proportions of standard mixes for SCC (control mixes)

Material	Mass used (kg/m^3)	
	NA	RA
Cement	535	535
Water	225	225
Coarse aggregate	1025	980
Fine aggregate	650	625
Wet density	2350	2330

Table 7 : Mix proportions of standard mixes for SCC with 30% PFA or RGD

Mix	Code	Mass (kg/m3)					
		Cement	PFA	RGD	Water	Coarse aggregate	Fine aggregate
5	RAC-SCC-30PFA	430	185	0	190	960	620
6	RAC-SCC-30RGD	430	0	185	190	960	620

Table 8 : Adjusted mix proportions of SCC concrete standard mixes

Mix	Code	Mass (kg/m^3)			
		Cement	Water	Coarse aggregate	Fine aggregate
1	NAC-SCC-CM (control mix)	545	255	1020	615
2	RAC-SCC-CM (control mix)	545	255	978	625

Table 9 : Workability of successful mixes of RAC-SCC

Mix	Code	w/c	w/b	Slump (mm)	Vebe (s)	Flow dia. (mm)	T_{500} (s)	T_{final} (s)	L-Box (PA)
1	NAC-SCC-CM	0.50	0.50	88	2	-	-	-	-
2	RAC-SCC-CM	0.50	0.50	73	4	-	-	-	-
3	NAC-SCC-0.9SP	0.40	0.40	277	-	700	2.23	15.6	0.90
4	RAC-SCC-1.1SP	0.40	0.40	260	-	683	2.37	13.1	0.83
5	RAC-SCC-1.0SP -30PFA	0.35	0.30	250	-	690	2.69	20.3	0.97
6	RAC-SCC-1.1SP-30RGD	0.35	0.30	267	-	715	1.54	10.7	0.97

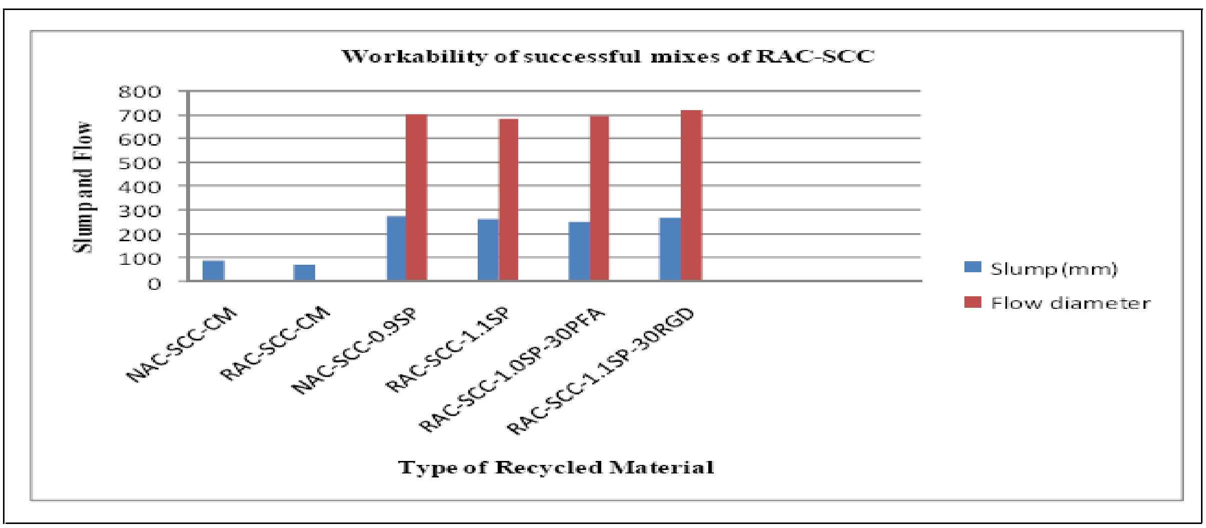

Figure 3 : Workability of successful mixes of RAC-SCC

Data in Table 8 showed that each mix is unique; each mix needed a certain amount of SP to satisfy SCC requirements. Concrete has to maintain its workability for a period of time to give operatives the chance to place it properly in the formwork. For successful mixes, the slump and slump flow were tested on the mix over the course of 90 minutes to see how the concrete would behave over time; loss of flow and slump were measured every 15 minutes. Data in Table 9 and Figure 3 show that slump was lost after one hour for mixes 3 to 6. This result indicates that the substitution of PFA and RGD to partially replace cement improves and maintains, and at the very least did not adversely influence, the workability of RAC-SCC. In particular, the RAC concrete mix without cement substitution (mix 4) has remarkably showed steady slump values within the period of 15 to 50 minutes; a larger drop was noticed within the first 15 minutes when compared with the similar mix with natural aggregate (mix 3), this however was expected due to the difference in absorption capacity. This feature was less pronounced in RAC-SCC mixes with PFA and RGD. A similar trend was observed for flow. The more water in a concrete mix the lower the quality at all ages. The w/b has very significant effects on both fresh and hardened properties of concrete. Strength and durability are considerably reduced when w/b ratio is increased; the less strong, the less durable the concrete. The effect of w/b ratio on the fresh properties of concrete restricts the choice of a low value on the strength, but SP can effectively remedy this situation. Aggregates form a considerable volume of concrete; typically 60-70% by volume. In addition to its serving as cheap filler, aggregate contributes to the strength of concrete, particularly when the strength of the paste matrix is low.

Table 10 : Slump and flow of SCC mixes at different times

Mix	Code	Average slump (mm) and flow diameter (mm) after a time of (min.):						
		5	15	30	45	60	75	90
3	NAC-SCC-0.9SP	280 (710)	267 (630)	259 (600)	235 (550)	210 (470)	85 (200)	44 (200)
4	RAC-SCC-1.1SP	277 (690)	229 (580)	212 (570)	191 (550)	183 (485)	117 (210)	48 (200)
5	RAC-SCC-1.0SP - 30PFA	285 (780)	280 (755)	272 (710)	260 (675)	253 (640)	227 (575)	149 (430)
6	RAC-SCC-1.1SP-30RGD	258 (680)	250 (650)	219 (605)	193 (575)	172 (505)	97 (240)	49 (200)

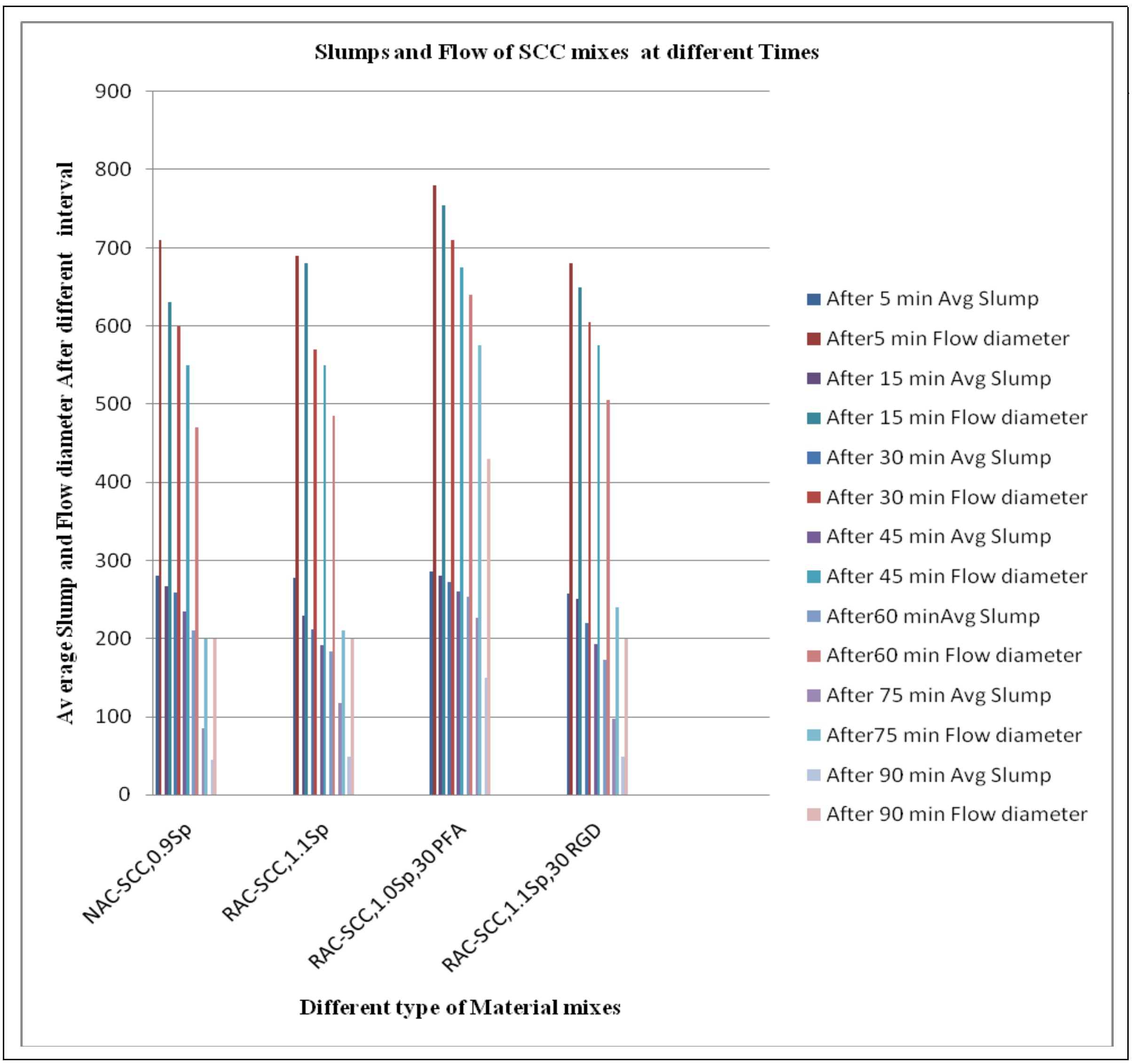

Figure 4 : Slumps and flow of SCC mixes at different time

Table 10 and Figure 4 show that the recycled aggregate mix with PFA was superior compared to other mixes when slump loss and flow are concerned; steady decrease of both values were observed. Even after 90 minutes, a slump of 145 mm and flow diameter of 430 mm were measured; this however can be attributed to the high initial slump which was basically comes from the higher design slump of the standard mix (60 -180 mm), the influence of SP, the spherical grain shape on fluidity, and the lower porosity of PFA grains. RAC exhibits similar behaviour to NAC, therefore concrete structures can be designed according to the prevailing theories used to design NAC members; however RAC is marginally deformable therefore attaining slightly more strain under similar stress (10 – 15 %).

Table 11 : Strengths of the SCC mixes

Mix	Code	Compressive strength (N/mm^2) after:			Tensile strength (N/mm^2) after:	Flexural strength (N/mm^2) after:
		28 d	56 d	90 d	28 d	28 d
1	NAC-SCC-CM	75.7	80.2	83.5	4.12	7.55
2	RAC-SCC-CM	58.9	61.3	63.0	3.71	6.63
3	NAC-SCC-0.9SP	92.9	91.8	93.4	5.11	12.1
4	RAC-SCC-1.1SP	60.7	61.5	62.2	4.16	9.16
5	RAC-SCC-1.0SP -30PFA	58.0	56.9	59.8	3.07	6.62
6	RAC-SCC-1.1SP-30RGD	48.2	55.2	56.8	2.91	5.91

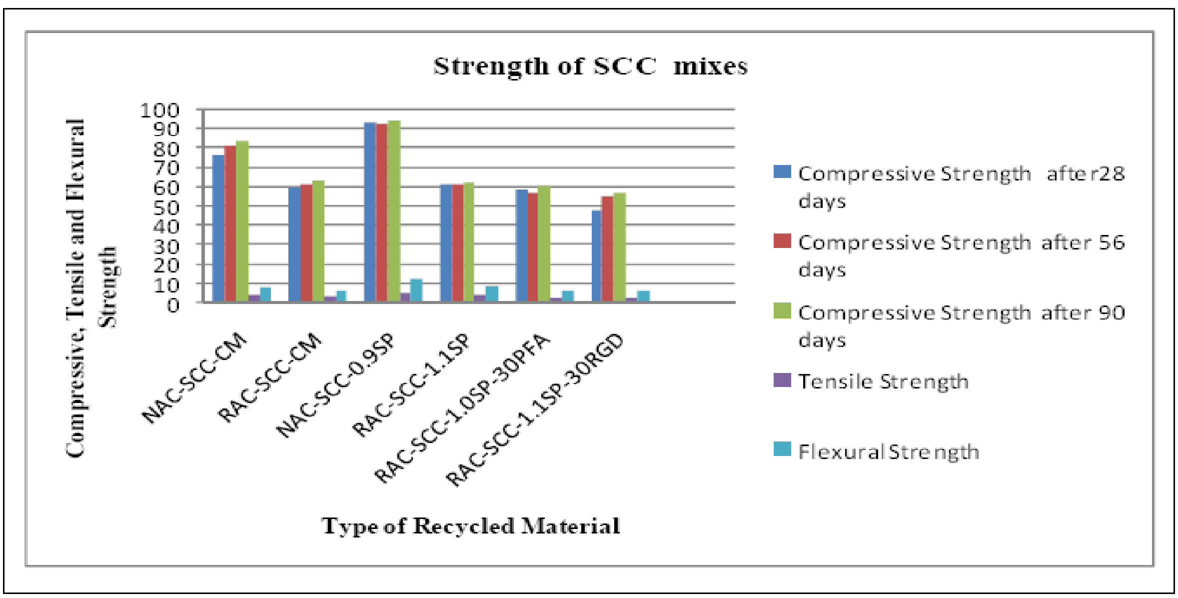

Figure 5 : Strength of SCC mixes

SCC is capable of filling all sections of complex shuttering perfectly, therefore will allow the engineer to design more complex connections, and facilitate the process of jointing pre-cast concrete units and SCC is ideal for deep concrete sections designed with dense reinforcement. Quality of RA and the level of replacement have an influence on mechanical and deformation characteristics of RAC. Result showed in Table 11 and Figure 5 the replacement level is increased, the strength and stiffness are decreased. Compressive strengths of RAC concrete reached 56 N/mm^2 after 28 days, and achieved higher strength with age reaching after 90 days. These were achieved for a mix designed to attain 40 N/mm^2 after 28 days curing, although the cement content was reduced by 25% thus contributing to its medium strength. Such strength levels, together with the well known benefits of PFA to the long-term performance of concrete, make this type of concrete more economical and satisfactory for many structural applications. The compressive strength of the super plasticized RAC with 30% PFA was much better than the RAC standard mix (improved by 33%) and similar to that of the NAC reference mix at 90 days. However, strength at 28 days was marginally below the target mean. RAC strengths at 28 days, 56 days and 90 days were achieved; these ranges practically cover the strength commonly required for several engineering applications. Results showed that NAC and RAC concrete mixes with 30% PFA as a substitute for the cement exhibited substantial increase of strength at later ages; 7 day compressive strengths improved by 80% and by about 90% for NAC and RAC concrete respectively (Table 11). A mild adverse influence of PFA on the tensile and flexural strength was observed. Strengths of concrete containing PFA increased over time, regardless of aggregate type. Therefore later age strengths of the resultant RAC are likely to increase. The achieved strengths of concrete with up to 50% replacement are good enough for many ordinary uses.

Results showed that the compressive strength of the SCC was increasing in a similar fashion to conventional concrete, regardless of aggregate type. The SP maintained workability, gave the required fluidity, contributed to form the slurry suspension needed to coat the aggregates and facilitate their relative movement. The SP also enabled the mix to be designed at low w/c ratio (Figure-6) therefore producing better strengths. It is well known that water has a great influence on the strength of concrete. The more water added, the weaker the concrete. The lower w/c ratio's influence clearly appeared in SCC without cement substitution; the compressive, tensile and flexural strengths at 28 days of NAC-SCC-0.9SP (Mix 3) were relatively enhanced. The increased strengths were most likely due to the enhanced matrix of the concrete (Figure-7).

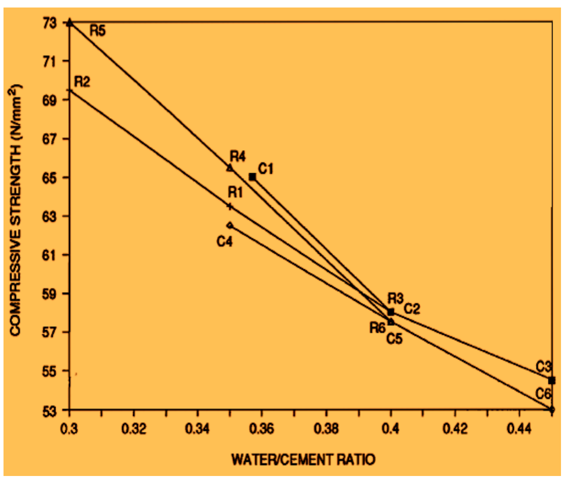

Figure 6 : Influence of water/Cement ratio on compressive strength

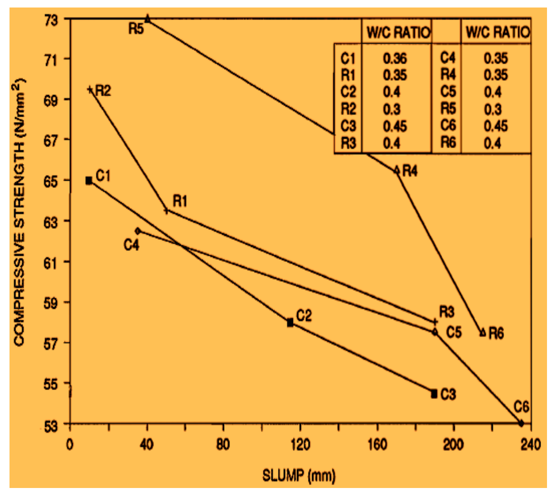

Figure 7 : Relationship between compressive strength and slump

A reduction of strengths, particularly the tensile strength, was observed when 30% of the cement was replaced by PFA and RGD compared to all other mixes, the 90 day compressive strengths were less than the target mean strength. The mix with PFA replacement was however better than its counterpart RGD mix. To make use of the observed benefit of PFA to the workability of SCC and perhaps to increase the strength, in addition to other well known advantages, PFA can be used as a supplement to cement instead of as a cement replacement. . A maximum strength reduction of 15% was observed when up to 50% of NA was replaced by RA. Bairagi & Kishore (1993)[33] reported that approximately 10% lower compressive strength, 0-20% reduction tensile and flexural strength, and 10-40% lower modulus of elasticity.

When PFA replaces fine aggregate in RAC concrete mixes, fine aggregate content is reduced and consequently, excess water available within the aggregate voids decreases. That may be developed by the relatively higher absorption capacity of RA and because the grain size of PFA is well below that of fine aggregate particles. Therefore, results showed that slump decreased as the level of PFA increased: the mix become less cohesive and drier.

It is believed that the impurities, particularly old cement paste stuck to RA have a significant influence on the strength of RAC. Several studies[52, 62, 53] concluded that adhered mortar from the original concrete plays an important role in determining performance with respect to permeability and strength. The absorption capacity is related to the size of RA; Hansen 1983[63] reported that the absorption capacity is about 3.7% for 4-8 mm RA, and about 8.7% for the 16-32 mm sizes, meanwhile it was only 0.8-3.7% for natural aggregates. Hansen & Narud 1992 shows that the volume percentage of mortar attached to natural gravel particles was between 25% and 35% for coarse recycled aggregates of 16-32 mm size, around 40% for 8-16 mm size and around 60% for 4-8 mm. A recent study (Etxeberria *et al.* 2007)[53] showed that crushed concrete comprises 49.1% of original aggregate plus the adhered mortar and 43% of original aggregate, 1.6% ceramic, 5.3% bitumen and 0.8% other materials. In this study, the total quantity of adhered mortar was estimated to be in the range 20-40% of the aggregate weight. This study also showed that the smaller the size of the aggregate the more adhered mortar. Therefore fine recycled aggregate would often contain more adhered mortar and have more absorption capacity. However, the utilisation of recycled fine aggregate for RAC concrete is usually avoided due to its higher absorption capacity and increased shrinkage[64]. The findings of the aforementioned studies are in agreement.

Bleeding (migration of mixing water to the top surface zone of the concrete section) due to use of RA is generally similar to that of natural aggregates. However, bleeding was observed to be reduced with recycled aggregates produced mainly from other materials rather than those originally produced from crushed concrete, such as the aggregates from cement, clay bricks, *etc*[65, 66] contends that the use of up to 30% RA to replace NA will not have significant adverse effects on RAC cube strength. For higher RA contents, minor alterations to the mix proportions may be needed to ensure that equivalent performance to NAC is achieved. Blending of natural and recycled aggregates did not result in significantly improved cube strength at high w/c ratio; the greatest improvement was less than 10%. Tensile strengths and elasticity modulus were found to follow the same trend as the compressive strength while the workability was little improved. In contrast, [67] reported that slump loss of concrete will be quite fast for RAC without pre-wetting of RA.

A study [68] reported that the results of concrete cast to contain 35% PFA cement replacement exhibited lower compressive strength, higher flexural strength and comparable modulus of elasticity of concrete at all ages as compared with the reference mixture containing no-fly ash.

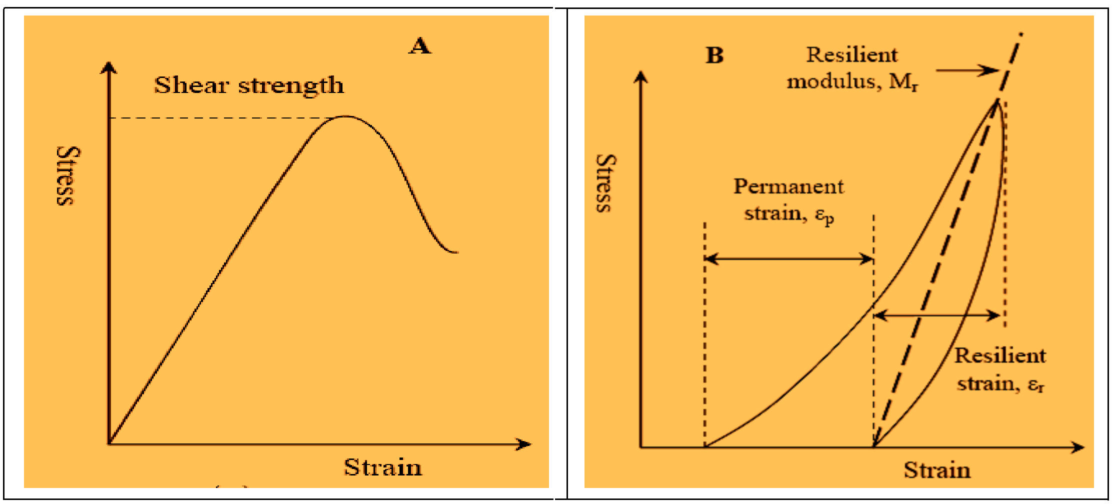

Figure 8 : (A) Monotonic loading to failure (B) strains in UGM during one load cycle

In general the monotonic failure triaxial tests are capable of providing the overall failure (strength) behavior of the granular materials and trends of the influence factors material type (Figure-8 a&b). However, there are limitations in order to precisely quantify the stress dependency of the strength behavior. One of the major limitations is the small magnitude of the maximum possible confining stress (80 kPa) that can be applied by the system compared to high levels of the failure stress ranging to 1800 kPa. The difference in magnitude between 20, 50 and 80 kPa confining stress is very small compared to the magnitude of the failure stresses.

VI. Geotechnical Properties of Crushed Brick

a) *Particle Size Distribution*

Coefficient of uniformity *Cu* is a basic shape parameter to define the grain size distribution and coefficient of curvature *Cc* is also used along with *Cu* [69]. Coefficient of uniformity *Cu* and coefficient of curvature *Cc* are defined by the following equations;

$$C_u = D_{60} / D_{10}$$

$$C_e = (D_{30})^2 / (D_{10})x(D_{60})$$

Where D_{60} = grain diameter (in mm) corresponding to 60% passing by weight

D_{30} = grain diameter (in mm) corresponding to 30% passing by weight

D_{10} = grain diameter (in mm) corresponding to 10% passing by weight

For site 1;

Before compaction

D_{60} = 8 mm; D_{30} = 1.8 mm; $D10$ = 0.18 mm

C_u=8/0.18=44.44

C_e= $(1.8)^2/(0.18)(8)$=2.25

After compaction

D_{60}=4.8mm; D_{30}=0.6mm; D_{10}=0.07mm

C_u=4.8/0.07=68.57

Ce= $(0.6)^2/(0.07)(4.8)$=1.07

For site 2

Before compaction

D_{60}=5.6 mm; D_{30}=0.6 mm; D_{10}=0.1mm

C_u=5.6/0.1=56

C_e= $(0.8)^2/(0.1)(5.6)$=1.42

After compaction

D_{60}=4.2 mm; D_{30}=0.56mm; D_{10}=0.07mm

C_u=4.2/0.07=60

Ce= $(0.56)^2/(0.07)(4.2)$=1.06

According AS 1726 Geotechnical site investigation (AS 1726, 1993)[70], all the crushed brick samples were fall under category gravel as more than half of the coarse fraction was larger than 2.36 mm and lesser than 63mm. However, since the percentage of fines (less than 75μm) is not less than 5% or greater than 12% and the samples satisfied with coefficient of uniformity and coefficient of curvature criteria, $Cu > 4$ and $1 < Cc < 3$ it could be either well graded gravel (GW) or silty gravel (GM) or clayey gravel (GC).

VII. Particle Density

a) Coarse particle

Particle density of crushed brick aggregates passing 19 mm and retaining on 4.75 mm are 2.67 t/m^3 and 2.65 t/m^3 for the samples from site 1 and site 2 respectively. Particle density of coarse crushed brick aggregates is lower than the crushed rock (class 3) aggregates.

b) Fine particle

Particle density of crushed brick aggregates passing 4.75 mm are 2.63 t/m^3 and 2.60mm for the samples from site 1 and site 2. Particle density of fine crushed brick aggregates is lower than the crushed rock (class 3) aggregates.

c) Water Absorption

i. *Coarse particle*

Water absorption of crushed brick aggregates passing 19 mm and retaining on 4.75 mm are 6.15 % and 6.20 % for the samples from site 1 and site 2 respectively. Water absorption of coarse crushed brick aggregates is higher than the crushed rock (class 3) aggregates.

d) Fine particle

Water absorption of crushed brick aggregates passing 4.75 mm are 6.87 % and 7.16% for the samples from site 1 and site 2. Water absorption of coarse crushed brick aggregates is higher than the crushed rock (class 3) aggregates.

e) Modified Compaction

Maximum density of crushed brick samples under modified compactive effort are 2.02 t/m^3 and 1.96 t/m^3 for the samples from site 1 and site 2 respectively. Optimum moisture content of crushed brick samples under modified compactive effort are 10.70 % and 11.5 % for the samples from site 1 and site 2 respectively.

f) Direct shear test

Direct shear test was carried out to find out the shear strength parameters of crushed brick samples. The normal stresses of 30kPa, 60 kPa and 120 kPa were applied on the crushed brick specimens in three consecutive tests.

g) Consolidated drained triaxial test

Consolidated drained triaxial tests were performed to find the apparent cohesion (c) and internal friction angle (ϕ) of the crushed brick samples. The effective confining pressures of 50 kPa, 100 kPa and 200 kPa were applied on the specimens in each test.

h) Shear strength

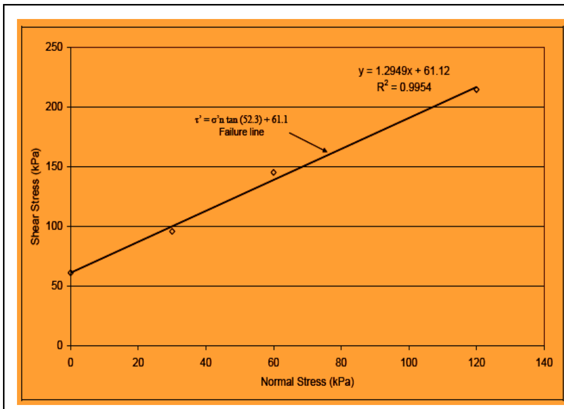

Figure 9 : Mohr- Coulomb envelope of crushed brick sample

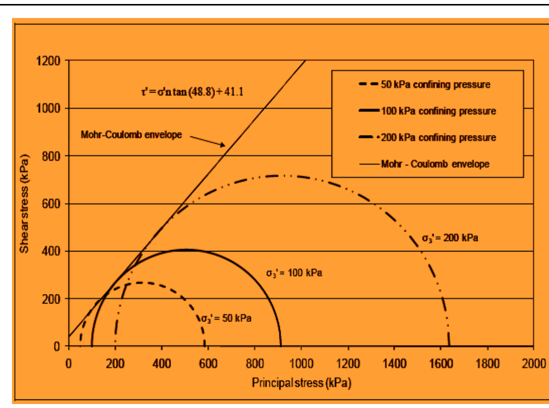

Figure 10 : Mohr"s circles and Mohr- Coulomb failure envelope for crushed brick samples (site 1)

Figure 9 and 10 shows the Mohr's circles and Mohr-Coulomb failure envelope of crushed brick samples under drained triaxial compression from site 1 and site 2. The Mohr-Coulomb envelope corresponding to the peak deviator stress is linear for the tested stress ranges and shown in conventional Mohr-Coulomb stress space. An internal friction angle (ϕ) of 48.8˚ and an apparent cohesion (c) of 41.1 kPa are corresponded to the Mohr Coulomb failure envelope of crushed brick sample sourced from site 1. Similarly, an internal friction angle (ϕ) of 44.6˚ and an apparent cohesion (c) of 65.5 kPa are corresponded to the crushed brick sample sourced from site 2. Even though, crushed brick aggregates are considered as non cohesive frictional material, it deviates form purely frictional behaviour due to the effect of confining stress. At higher confining pressures, particle became flattened at contact points, sharp corners are crushed and interlocking also reduced.

VIII. Conclusion

In terms of stress-strain relationship, RAC exhibits similar behaviour to NAC, therefore concrete structures can be designed according to the prevailing theories used to design NAC members. As the strength of RAC is not as high as that of NAC, the cement content needs to be increased by 20-30% for RAC mixtures to achieve similar compressive strength. To produce RAC concrete with similar workability to NAC concrete, water content needs to be increased by 5-8% depending on the aggregates absorption capacity; cement content must be also increased to keep w/c constant. RA is mixed in a saturated state e.g. not in surface dry condition the mechanical properties may be significantly influenced. SP and/or PFA can purposely be used instead. PFA generally slightly reduces the early age strength of concrete, but strengths continued to improve over time. While strength may be one of the most important concrete properties that control its performance. The use of recycled aggregates in concrete prove to be a valuable building materials in technical, environment and economical respect. As SCC can be easily pumped into high-rise concrete buildings; the increased volume of concrete will have a positive influence on the construction time and therefore the rate at which the whole structure is erected. In addition it requires fewer workers in comparison to traditional methods.

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