Comparing the Compressive Strengths of Guanapo Recycled Aggregate Concrete with that of its Waste Material.

Jason R.F. Lalla
Trinidad and Tobago Housing Development Corporation, 44-46 South Quay, Port-of-Spain, Trinidad And Tobago, jrflalla@hotmail.com

Abrahams Mwasha
University of the West Indies, St. Augustine, Trinidad and Tobago, amwasha@yahoo.com

ABSTRACT

As part of the results of an investigation to determine and compare the compressive and splitting tensile strength parameters of concrete manufactured using natural and recycled Guanapo coarse and fine aggregates, this paper is a continuation of the results presented in a paper by Lalla & Mwasha (2011) and is intended to highlight the result of comparisons of compressive strengths of recycled aggregate concrete (RAC) and its source material. Compressive strength testing was conducted according to ASTM C39 and correlations on the data obtained from testing were determined using the one way ANOVA statistical method. The results of this portion of the study show that it is indeed a viable option to use recycled Guanapo aggregates as a suitable substitute to natural aggregate and that waste material from construction demolition waste (CDW) can easily be recycled to produce concrete of comparable properties to that of its source waste material.

Keywords: Recycled Aggregate, Guanapo Aggregate, Compressive Strength, Waste Material, ANOVA

1. INTRODUCTION

Construction and demolition waste represents both the largest waste stream as well as an increasingly utilized supply of material to the construction industry in many parts of the world. On the other hand, it is now widely recognized and steadily accepted that there is a significant potential for reclaiming and recycling demolished debris for use is value-added applications to maximize environmental and possible economic benefits. Indeed, it is widely acknowledged that recycling of CDW for reuse as coarse aggregate in new concrete production is technically viable and under certain circumstances environmentally sustainable and economically feasible route to convert this material into a valuable resource (Limbachiya 2010).

In Trinidad & Tobago, the production of CDW as well as the demand for construction materials have increased dramatically over the past ten years, mainly due to a construction boom which has only began to taper recently due to the global economic slowdown. Nevertheless, the demand for construction aggregates in particular has ballooned to a point where the lush tropical rainforests of the Northern Range Mountains have begun to suffer illegal quarrying operations. Resulting from this, a greater effort is needed by those in the construction industry and government who can affect policies to ensure that better utilization of CDW becomes mainstream practice in Trinidad and Tobago.

2. PROGRESS ON THE USE OF RECYCLED AGGREGATES INTERNATIONALLY

The recycling of CDW for manufacturing RAC is not a new idea as the earliest known study of this nature can be attributed to Glushge in Russia (Glushge, 1946). It is expected that the world demand for construction aggregates is forecasted to expand 2.9% annually though to 2013 to 28.7 billion tonnes (World Construction Aggregate,

2009) as natural aggregates are the major component for the manufacturing of PCC and are known to occupy 55-80% of concrete volume.

Initially the recycling of demolished concrete was carried out after the Second World War (Hansen, 1992). The use of RAC started mainly about 60-65 years ago when large quantities of concrete debris became available from World War II damaged structures and suddenly a great need for aggregate rose up when these structures were to be re-constructed or repaired (Kheder and Al-Windawi, 2005). In recent years the recyclable potential of CDW has made it a target of interest and the main focus of waste management policies encouraging minimization, reuse, recycling and valorization of the waste as opposed to it final disposal in landfills (Esin & Cosgun, 2007; Solis-Guzman *et. al*, 2009). Such policies are yet to be initiated and enforced in the local construction industry of Trinidad and Tobago.

The largest proportion of demolition waste are generated from concrete rubbles and it has been shown from numerous studies over the years that crushed concrete rubble after separated from other CDW and sieved, can be used as a substitute for natural coarse aggregates in concrete or as a sub-base layer in pavements (Hansen,1992; Mehta *et. al,*1993; Collins, 1994; Sherwood, 1995). Among the conclusions by Frondistou-Yannas (1977) was that recycled concrete suggest itself as a useful substitute for aggregate in regions where concrete disposal is a problem or where natural aggregates are not accessible. Properties such as workability, compressive strength and elastic modulus were found to be very similar and even match in some cases to that of conventional concrete. Buck (1977) also showed that it is possible to produce new concrete from crushed concrete coarse aggregate. However, Buck (1977) studied concrete mixes that contained recycled concrete as coarse aggregate as well as mixes that contained recycled concrete both as fine and coarse aggregate. His findings are that recycled concrete can best be used as a substitute for coarse aggregate only.

Utilization of recycled concrete has been taking place and steadily growing every year. In the United Kingdom (UK) 2001, 42 million tonnes of construction and demolition waste including concrete was recycled. That represents an increase of 382% since the early 90s whereby the use of primary aggregates for construction has decreased by 28% between the years 1989 to 2002.

In addition, it was proposed by Poon *et. al* (2002) that the replacement level of recycled course aggregate at air-dried state should not exceed 50% to produce concrete having less workability loss and higher compressive strengths. On the other hand, it was observed from tests carried out by Khatib (2005) that the 91-day compressive strength of concrete having recycled fine aggregate with a replacement level below 50% was similar to that of concrete with only natural aggregates and only 10% reduction was recorded for concrete with a replacement level of 100%. As reported by Li *et. al*. (2004), RAC with a water/cement ratio of 0.5, volume ratio of coarse aggregate of 42%, 100% natural river sand, 0% crushed brick and as-is recycled aggregate without water-washed aggregate exhibited in a concrete slump of 180mm and a compressive strength of 30.17 MPa at 28 days which is applicable for most concrete structures. Tu *et. al.* (2006) also tested high performance concrete having recycled aggregates with high water absorption and concluded that that recycled aggregates have a minor effect on the initial slump of concrete but an adverse effect on the workability with time.

Despite all this, the limited use of recycled aggregate in structural concrete is due to the inherent deficiency of this type of material in comparison with natural, normal weight aggregate; recycled aggregate are weaker, more porous and have higher values of water absorption. The results of research studies by Hendriks *et. al.* (1998) show that, when recycled aggregates obtained from crushed concrete are used to replace up to 20% by weight of the coarse natural aggregate in concrete, little effect on the properties of concrete is noticed(Kumutha & Vijai. 2010). The concrete strength decreases when recycled concrete was used (Barra *et. al.*, 1996) and the strength reduction could be as low as 40% (Katz, 2003) and Chen *et. al.*, 2003). However, no decrease in strength was reported for concrete containing up to 20% fine or 30% coarse recycled concrete aggregate, but beyond these levels, there was a systematic decrease in strength as the content of recycled aggregates increased (Dhir *et. al.*, 1999).The results of this study showed similar trends for the compressive and splitting tensile strengths as presented in the a preceding paper by Lalla and Mwasha (2011) for the latter strength parameter.

Despite the economic and environmental benefits of concrete produced with recycled concrete aggregates (RCA) dubbed RCA-concrete and steadily increased usage of the material, the construction industry has not totally embraced it, especially for structural applications, partly due to previous findings that have concluded that RCA-concrete is inherently inferior to conventional concrete made with natural aggregate (Fathifazl, 2009).

Many a researcher have conducted studies on RAC and concluded that the material may have inherent defects that may be as result of the condition of the recycled aggregate and the method of processing, however they have compensated for this lack of properties by enhancement of the material using mineral admixtures. Amongst the conclusions of a study by Kou *et. al.* (2011) to compare the natural and recycled concretes prepared with the addition of different mineral admixtures, they observed that the results show that the contributions of the mineral admixtures to performance improvement of the recycled aggregate concrete are higher than that to the natural aggregate concrete.

Additionally, previous research results on the mechanical behavior of recycled aggregate concrete have been reviewed by Hansen (1992) and Li (2004). It was revealed that, in fact, none of the previous results indicated that the recycled aggregate concrete is unsuitable for structural applications. Recent investigations on the performance of beams (Sogo *et. al.*, 2004; Maruyma *et. al.*, 2004; Dolara *et. al.*, 1998), columns (Konno *et. al.*, 1997), beam-column joints (Corinaldesi, 2003) and slabs (Cyllok, 2002) made from recycled aggregate concrete all gave positive results, which further supports and encourages the possibilities of applying recycled aggregate concrete in civil engineering structures. The results of this study also agree with these positive findings for the greater application of RAC in construction.

Therefore, this paper reports on the potential of RAC to achieve compressive strengths comparable or greater in some instances than that of its source waster material in order to promote the recycled of CDW in Trinidad and Tobago.

3. PROGRESS ON USE OF RECYCLED AGGREGATES LOCALLY

The use of recycled aggregates and RAC in Trinidad and Tobago is still minimal at best; however interest in its future usage in the local industry is beginning to increase as evidenced by this paper and additional research being carried out at the University of the West Indies. Additionally, the Trinidad Cement Limited (TCL) recently conducted an extensive seminar on the use of recycled aggregates in T&T not to mention the Ministry of Housing and the Environment paying a little more attention to construction of homes in a more sustainable and environmentally friendly way.

In T&T, recycled aggregates are still only used in the most basic of forms as road filler in road construction and in low-level applications due to impurities and defect associated with recycled aggregates (Mwasha and Mark 2008). Recent renovations and reconstruction of the administration building, chemical engineering department and senior common room at the University of the West Indies (UWI), St Augustine campus is one example of a huge source of recycled aggregates locally. Recently with the creation of the campus recycling committee, greater volumes of construction and demolish wastes will be turned to useful aggregates which would serve to supplement the demand for natural aggregates for construction projects at UWI, St. Augustine in addition to minimizing the demolition wastes that are deposited in the Beetham Land Fill. Presently, the Beetham Land Fill is used to deposit 65% of solid waste produced in Trinidad (SWMCOL 2010). The UWI, St Augustine campus recycling committee has come up with many ways to minimize solid waste reaching the Beetham landfill whilst at the same time the People‟s Partnership Government manifesto of 2010 has emphasized the need for sustainable development with environmental preservation and management being the cornerstone of such a drive. This paper aims to present the results of testing the recycled aggregate concrete materials thereby showing that the recycled aggregate materials can be used to manufacture concrete that meets with local and international standards. In order to do this, the recycled aggregate material was tested and compared with conventional concrete products of the same mix design. This information would be vital in ensuring customer confidence in recycled aggregate concrete products and to gain and maintain a stable foothold in the local construction industry.

3.1 Availability of Natural and Recycled Aggregates in T&T

In Trinidad and Tobago, the local quarrying industry comprises of fifty-six (56) active quarries of which thirty-eight (38) produce mainly sand and gravel. The total output of the quarrying sector for 2002 was approximately seven (7) million cubic yards (5.3 million cubic meters) of which 4.5 million cubic yards (3.4 million cubic meters) were sand and gravel (Draft Quarry Policy for Trinidad and Tobago 2005).

The majority of quarrying operations in Trinidad occur within the Northern Range of mountains, which are an extension of the Andean Mountains in the South America. This area has primeval tropical rainforests, renowned for their diversity of flora and fauna. Typically, the rainforest includes over 2,300 plant species with 700 species of orchids, and provides a habitat for over 430 species of birds, 620 species of butterflies, 100 species of mammals, 70 species of amphibians and freshwater fish, and 70 species of reptiles. Unfortunately, it should be noted that the regions with the greatest biodiversity are also often the same locations, where conservation measures are the most difficult to implement because of the limited natural resources, difficult access, and poor enforcement of laws for controlling poaching and habitat destruction due to illegal mining.

From a geological perspective, the Northern Range region comprises primarily low grade metamorphic rocks of the Caribbean Group belonging to the Maraval formation. Limestones and recrystallized limestones are the most common rocks of the region, inter-laid by thinly bedded phyllitic limestones at some locations together with inter-bedded phyllites which are often calcareous. These are the oldest rocks in the Northern Range.The majority of aggregates used for construction in Trinidad and Tobago are natural aggregates derived from either limestone or Quartzite rock. The availability and destructive process of obtaining these rocks in small islands of the Caribbean has contributed colossal negative environmental consequences. The need for reducing the environmental impact of concrete should be pursued by each one involved in these industry especially concrete technologists who are currently challenged to lead and develop concrete technology in a way that protects environmental quality whilst projecting concrete as a construction material of choice. Sustainability should be responsibly addressed regarding climate change resulting from the increased concentration of global warming gases caused by the extraction and manufacturing process of concrete components (Mehta, 2001, Concrete International, 2001). Given the current decrease in availability of relatively cheap and high quality aggregate and the increase in the demand for such materials for the production of concrete in Trinidad and Tobago, it is certain that new sources of aggregate will have to be identified. This research paper presents the results of such tests which includes compressive strength and splitting tensile strength of concrete and it seeks to give a comparison of both naturally made concrete and recycled Guanapo Quartzite aggregate concrete, as well as comparisons involving recycled aggregate concrete and the original refuse concrete the recycled aggregates were manufactured from.

4. Experiment and Testing

4.1 Materials

4.1.1 Portland Cement And Water

The composition of typical cement used in this experiment is given in European Standards ENV 1974[9].

Natural (ordinary tap water) pipe borne water was used. Natural pipe borne water in Trinidad is slightly acidic. The content of humic and organic acids was at minimum.

4.1.2 Natural And Recycled Aggregates

Quartzite aggregates used in this work were extracted from a number of quarry sites in Valencia, Trinidad. Guanapo Quartzite is classified as a non-foliated metamorphic rock. This is probably because these rocks were once exposed to high temperature conditions, but not to high directional pressure conditions. The parent rock for the Guanapo quartzite was probably a quartz-rich sandstone deeply buried and rising temperature fused the grains together forming highly strong aggregates with low porosity. These aggregates are highly weather-resistant making them excellent construction material. The Valencia quartzite tends to have a sugary appearance, and when broken, the fractures cut through the sand grains and not around them as with sandstone. The specific gravity of these aggregate was 2.65 and the moisture contents of approximately 2.25%. The variations of moisture content in the mixes were adjusted accordingly, taking into account this increase in moisture so as to maintain specified water/cement ratios. All coarse and fine recycled aggregates used to produce the recycled aggregate concrete were manufactured at the University of the West Indies, Civil Structural Laboratory, using refuse 150mm concrete cylinders tested in compression, obtained from the Geotechnical Laboratory of Trintoplan Consultants Limited. All natural aggregates used to produce natural aggregate concrete were obtained from the laboratory storage depots and the natural aggregates were sourced from the National Quarries Limited Guanapo quarry.

5. METHODOLOGY

5.1 MANUFACTURING AND TESTING OF SAMPLES

5.1.1 MIX DESIGN

The concrete mix used in this study was designed to achieve a 28 day concrete compressive strength of 30MPa as the design strength of the source waste material concrete was the same. The mix design was carried out in accordance with the Absolute Volume Method from Section 6.2 ACI 211.1-91 using metric units of measure. Table 1 shows the proportions of materials and mix ratios that constitute the mix design of the source waste material (Seereeram Brothers Limited) and this study‟s new mix design.

Table 1: Mix Design Quantities and Ratios (based on 1m^3 batch)

Concrete Mix	Concrete Design Strength/MPa	Water Content/kg	Cement Content/kg	Coarse Agg. Content/kg	Fine Agg. Content/kg	Water/Cement Ratio	Coarse/Fine Ratio
Source Waste Material	30	176	395	1050	765	0.45	1.37
New Mix Design	30	205	380	930	830	0.54	0.62

5.1.2 MANUFACTURING OF CONCRETE SAMPLES

Two types of concrete were manufactured; firstly natural aggregate concrete (NAC) and secondly, recycled aggregate concrete (RAC). Different proportions of RA and NA were used to manufacture four variations of concrete. For each of the four variations of concrete (sixty (60) cylinders per concrete variation), two batches (thirty (30) cylinders per concrete batch) of each concrete variety were manufactured. Natural Aggregate Mix 1 and Mix 1A contained no RA and consisted of 100% NA. Recycled Aggregate Mix 2 and Mix 2A contained 25% RA and 75% NA, whilst Recycled Aggregate Mix 3 and Mix 3A contained 50% RA and 50% NA. Finally, Recycled Aggregate Mix 4 and Mix 4A contained 100% RA and 0% NA. It should be noted that the proportional percentages indicated for each mix refers to both the coarse and fine aggregates.

5.1.3 Testing of Samples

Two types of tests were performed on the 150mm concrete cylinders samples produced. These two tests were compressive strength and splitting tensile strength testing and they were carried out according to ASTM C39 and ASTM C496 respectively. For each of the concrete batches, thirty (30) cylinder samples were tested in compressive strength and splitting tensile strengths respectively and for each thirty sample set; six (6) samples were tested at each age break of 3, 7, 14, 21 and 28 days. The results of both the compressive strength and splitting tensile strength testing were presented in a previous paper by Mwasha and Lalla (2011) however, this paper only presents the results of the compressive strength testing of the RAC samples in comparison to the compressive strengths of the waste material concrete cylinders (also 150mm cylinder size).

5.1.4 Testing of Aggregates

Various tests were performed on both the NA and RA to provide supportive data for the tests performed on the concrete cylinders produced from the concrete batches mixed. Aggregate tests performed include moisture content, specific gravity and absorption and particle size analysis. The results of these aggregate tests will be presented and correlated to the achieved strengths in subsequent papers.

6. Analyses

Statistical analyses of data obtained from the concrete testing phases of this investigation were carried out using one-way ANOVA method. Microsoft Excel 2007 software was used to perform this analysis.

Analyses to determine significant differences were carried out in three sections as follows:

1) Analysis of Splitting Tensile Strength Results (NAC versus RAC).
2) Analysis of Compressive Strength Results (NAC versus RAC).
3) Analysis of Original/Refuse Compressive Strength versus RAC Compressive Strength Results.

It should be noted that the results and analysis of the first two points listed above (i.e. Analysis of Splitting Tensile Results and Analysis of Compressive Strength Results) were presented and discussed in a previous paper by the authors Mwasha and Lalla (2011) and only the third point above will be explored in the subsequent sections.

Of the many waste material concrete cylinders used in this study and the substantial compressive strength data obtained from the prior, compressive testing of these cylinders, six representative values for compressive strength had to be chosen from the mass of compressive strength data collected. These six representative samples were compared to the six, twenty-eight day average compressive strengths obtained for each of the three RAC varieties produced (See Section 5.1.2). Only twenty-eight (28) day compressive strengths were used for this analysis.

The criterion for selecting the six representative compressive strengths from the waste material concrete compressive strength data set was as follows:

1) The highest compressive strength value observed.
2) The lowest compressive strength value observed.
3) The average compressive strength value calculated from the data set.
4) The most frequently occurring compressive strength value observed (i.e. Mode).
5) The second most frequently occurring value observed.
6) The third most frequently occurring value observed.

The averages of the six (6) waste material concrete cylinders CS and that of each of the three (3) RAC batches were compared using one-way ANOVA to determine the significant differences and the variance of each group.

7. Results and Discussion

Tables 2 and 3 below give the twenty-eight (28) day waste material representative sample strengths and strengths of the three (3) RAC batches (tested in compression) respectively.

Table 2: Waste Concrete Cylinder Representative Compressive Strengths

Group – Waste Concrete Cylinders			
Sample ID	**Sample Age**	**Sample Compressive Strength/ MN/m^2**	**Sample Description**
REP 1	28	39.00	Highest Value
REP 2	28	29.82	Average Value
REP 3	28	31.00	Most Occuring
REP 4	28	30.00	2nd Most Occuring
REP 5	28	29.00	3rd Most Occuring
REP 6	28	15.60	Lowest Value

Table 3: 28-Day Recycled Aggregate Compressive Strengths

Sample Age / Days	Sample ID And Compressive Strength / MN/m^2						Average Compressive Strength / MN/m^2
	Group – Recycled Aggregate Mix 2						
	$RA_{25}25$	$RA_{25}26$	$RA_{25}27$	$RA_{25}28$	$RA_{25}29$	$RA_{25}30$	
28	30.4	30.1	29.4	28.0	31.1	29.4	29.73
Sample Age / Days	**Sample ID And Compressive Strength / MN/m^2**						**Average Compressive Strength / MN/m^2**
	Group – Recycled Aggregate Mix 3						
	$RA_{50}25$	$RA_{50}26$	$RA_{50}27$	$RA_{50}28$	$RA_{50}29$	$RA_{50}30$	
28	38.3	36.6	34.5	34.7	34.1	35.4	35.60
Sample Age / Days	**Sample ID And Compressive Strength / MN/m^2**						**Average Compressive Strength / MN/m^2**
	Group – Recycled Aggregate Mix 4						
	$RA_{100}25$	$RA_{100}26$	$RA_{100}27$	$RA_{100}28$	$RA_{100}29$	$RA_{100}30$	
28	33.9	32.6	35.7	35.3	34.3	33.4	34.20

Table 4: Summary of Results of Analysis Performed For Comp. Strength Data of RAC Vs Source Material

Twenty-Eight (28) Day Compressive Strength Statistical Data Analysis				
Groups	**Sample Count**	**P Value Bet. Groups (Significance = 0.01)**	**Average Compressive Strength**	**Variance**
Waste Material Concrete Cylinders	6	0.021086	29.0700000	57.04060000
Recycled Aggregate Mix 2 (25% RA)	6	0.021086	29.7333333	1.134666667
Recycled Aggregate Mix 3 (50% RA)	6	0.021086	35.6000000	2.520000000
Recycled Aggregate Mix 4 (100% RA)	6	0.021086	34.2000000	1.352000000

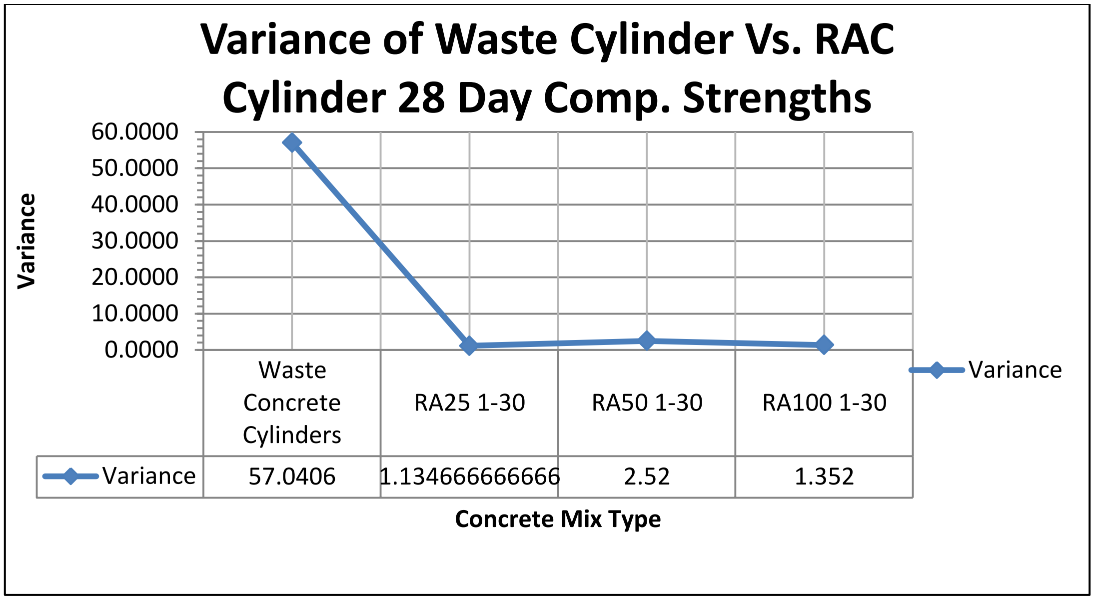

Figure 1: Graphical Representation of Variance of Waste Concrete and RAC Compressive Strengths

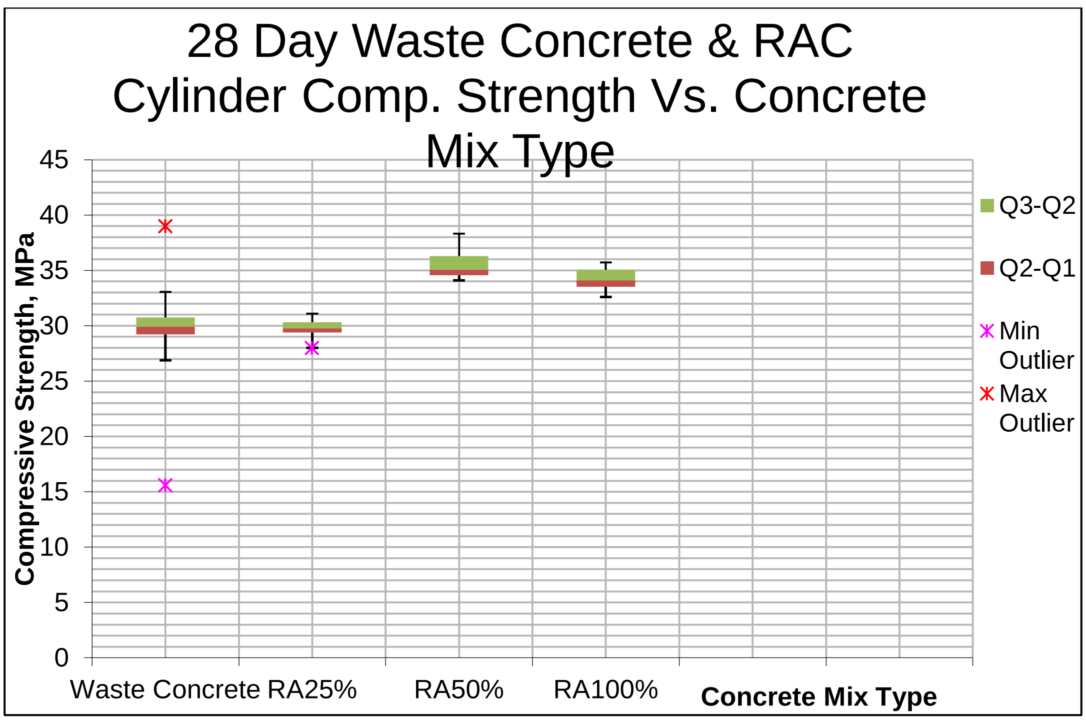

Figure 2: Box and Whisker Plot of Variance of Waste Concrete and RAC Compressive Strengths

The results of the 28 day compressive strength data collected in this study indicate that the recycled aggregate concrete mixes (which are of the same mix design as the waste material concrete mix) outperform the waste material concrete mix in terms of average twenty-eight day compressive strengths and rates of hydration. The three recycled aggregate mixes which contained 25%, 50% and 100% recycled aggregate all attained the design strength of 30MPa at twenty-eight days whilst the recycled aggregate mixes that contained 50% and 100% recycled aggregates both achieved the design strength at fourteen days and surpassed the 30MPa mark at twenty-eight days. To elaborate on the implications of the statistical data presented in Tables 4, let us look at Concrete

Mix 2 (25% RA). This concrete mix exhibited the least CS variance at 28 days old as compared to the waste concrete and the other two RAC batches. Also, the variance observed in the other RAC batches indicate that greater replacement percentages of RA can be used to produce RAC consistently attaining the set mix design strength. Concurrently, the P-value observed between groups of data was less than the significance value of 0.01 used for analysis which suggests that the „null" hypothesis (which assumes that there is no difference between the compressive strengths of the groups) can be rejected. As a result of rejecting the „null" hypothesis, we safely assume that the percentage of recycled aggregate added to each concrete mix does indeed affect the compressive strengths achieved as can be observed from the data collected for at the 28 day age break. Therefore, from the compressive strength results obtained and the statistical data calculated, it has been shown that it is very possible to reproduce with very little variance, the design strength of the waste material concrete using the recycled aggregates produced from the very same waste concrete.

8. CONCLUSION AND RECOMMENDATIONS

The data collected from the CS testing of RAC batches as compared to that of its waste material concrete show that RAC can indeed achieve the CS of it source material quite easily , with very little variance in strengths, and at times, surpass the CS of the original waste material. From the statistical analyses, the RAC batch with 25% replacement exhibited the least variance whilst the other two RAC batches also had very low variances when compared to the CS data set of the waste material.

The results of this portion of the study is indicative of the potential for reuse of CDW however it should be noted that this is an isolated, very controlled study whereby the waste material (tested 150mm concrete cyclinders) was collected from a laboratory and the variability of the composition, mix and impurities present in the waste material were negligible. Therefore greater research is needed to explore the effects of various sources of CDW in T&T and the differing properties of such materials on the properties of RAC.

REFERENCES

American Society for Testing Materials (ASTM). 2009. *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. ASTM C39

America Concrete Institute (ACI). 2009. *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete.* ACI 211.1-91

Barra de Oliviera M., E. Vasquez. 1996. "The influence of retained moisture in aggregates from recycling on the properties of new hardened concrete." *Waste Management.* Vol.169(1-3):113-117

Buck, Alan D. 1977. "Recycled Concrete as a Source of Aggregate". *Journal of the American Concrete Institute.* Vol. 74, No. 5, May 1977.

Chen H.J., T. Yen, K.H. Chen. 2003. "Use of building rubbles as recycled aggregates". *Cement & Concrete Research.*Vol.33:125-132

Collins R.J..1994. "The use of recycled aggregates in concrete". *BRE Report, Building Research Establishment, U.K.* May

Corinaldesi V.. 2003. "Recycled aggregate concrete under cyclic loading". *Proceedings of the International Symposium on Role of Concrete in Sustainable Development, University of Dundee, Scotland.*3-4 Sep,509-518

Cyllok M.. 2002. "Concrete with recycled aggregate: laps and cracks". *Proceedings of the 4th International PhD Symposium in Civil Engineering, Munch, Germany.*19-21 September, pp72-73

Dolara E., G. Di Niro, R. Cairns. 1998. "Recycled aggregate concrete pre-stressed beams". *Proceedings of Conference on Sustainable Construction: Use of Recycled Concrete Aggregate,University of Dundee, Scotland.* 11-12 November, pp255-262.

Esin T., N. Cosgun. 2007. " A study to reduce construction waste generation in Turkey". *Build Environ 2007.* Vol.42:1667-74

Fathifazl, Gholamreza., A. G. Razaqpur, O. Burkan Isgor , Abdelgadir Abbas, Benoit Fournier, and Sima Foo. 2007. "Flexural Performance of Steel-Reinforced Recycled Concrete Beams". *ACI Structural Journal* V. 106, No. 6, November-December 2009

Frondistou-Yannas, S. 1977. "Waste Concrete as Aggregate for New Concrete". *Journal of the American Concrete Institute.*Vol. 74, No. 8, August 1977.

Gluzhge, P.J. 1946. "The Work of Scientific Research Institute". *Gidrotekhnicheskoye Stroitel'stvo* Vol. 4:27-28

Hansen T.C..1992. " Recycling of demolished concrete and masonry". *E&FN Spon, London*

Hendriks C.F. and H.S. Pieterson. 1998. " Concrete: durable but also sustainable." *Proceedings of International Conference on the Use of Recycled Concrete Aggregates.* 1-18 Thomas Telford, U.K.

Katz A.. 2003. " Properties of concrete made with recycled aggregate from partially hydrated old concrete". *Cement and Concrete Research.* Vol.33:703-711

Khatib J.M. 2005. "Properties of concrete incorporating fine recycled aggregate". *Cement & Concrete Research.* Vol.35:763-769

Kheder, G. F., and S. A. Al-Windawi. 2005. "Variation in mechanical properties of natural & recycled aggregate concrete as related to the strength of their binding mortar". *Materials & Structures* 38 (Aug-Sep2005):701-709

Konno K., Y. Sato, Y. Kakuta, M. Ohira. 1997."Property of recycled aggregate column encased by steel tube subjected to axial compression." *Transaction of the Japan Concrete Institute* Vol.19:231-238

Kou S., C. Poon, F. Agrela. 2011. " Comparisons of natural and recycled aggregates concretes prepared with the addition of different mineral admixtures". *Cement and Concrete Conposites.* Vol.33:788-795

Kumutha R. and K. Vijai.2010. "Strength of concrete incorporating aggregates recycled from demolition waste". *ARPN Journal of Engineering and Applied Studies.* Vol.5, No. 5

Li J.B..2004. " Study on mechanical behaviour of recycled aggregate concrete". *Master Thesis, Tongji University.*

Limbachiya M.C.. 2010. "Recycled aggregates: production, properties and value-added sustainable applications". *Journal of Wuhan University of Technology, Mater.* Dec. 2010

Maruyma I., M. Sogo, T. Sogabe, R. Sato, K. Kawai. 2004. " Flexural properties of reinforced recycled concrete beams". *Proceedings of the International RILEM Conference on the Use of Recycled Materials in Buildings and Structures, Barcelona, Spain.* 8-11 November, pp610-618

Mehta, P. Kumar and P.J.M Monteiro. 1993. Concrete: Structures, Prop., & Materials. New Jersey, Prentice Hall

Mehta, P. Kumar. 2001. "Reducing the environmental impact of concrete". *Concrete International*, October 2001.

Mwasha A. and J.R.F. Lalla. 2012. "Analysing the strength parameters of concrete manufactured using natural & recycled guanapo aggregates". *The West Indian Journal of Engineering.* Vol.34, Nos.1/2,Jan. 2012, pp.44-51

Mwasha, A. and J. Mark. 2008. "Potential for the use of recycled aggregates in Trinidad and Tobago. Quelle: Construction in Developing Economies". Available at http://www.baufachinformation.de/publikationen.jsp?s=Aggregat

Poon C.S., S.C. Kou, L. Lam. 2002. "Use of recycled aggregates in moulded concrete bricks and blocks". *Construction and Building Materials.* Vol.16,pp.281-289

Sherwood P.T.. 1995. "Alternative Materials in Road Construction". *Thomas Telford, London.*

Sogo M., T. Sogabe, I. Maruyma, R. Sato, K. Kawai. 2004. " Shear behaviour of reinforced recycled concrete beams". *Proceedings of the International RILEM Conference on the Use of Recycled Materials in Buildings and Structures, Barcelona, Spain.* 8-11 November, pp610-618

Solis-Guzman J., M. Marreno, M.V. Montes-Delgado, A. Ramirez-de-Arellano. 2009. " A Spanish model for quantification and management of construction waste". *Waste Manage 2009.* Vol.29:2542-8

The Congress of the People 2010. *People's Partnership Manifesto 2010.* www.coptnt.com/ver03/media/peoples-manifesto-2010.pdf (Accessed on September 4th 2010)

Trinidad and Tobago Solid Waste Management Company Limited (SWMCOL) 2010. http://www.swmcol.co.tt/

Tu T.Y., Y.Y. Chen, C.L. Hwang. 2006. "Properties of HPC with recycled aggregates". *Cement & Concrete Research.* Vol.36, pp.943-950

World Construction Aggregates. 2009. *Industry Study with Forecasts for 2013 & 2018* Study #2564, December 2009 http://www.freedoniagroup.com/brochure/25xx/2564smwe.pdf (Acc. on Feb. 28th 2010)

Wikipedia 2010. *Analysis of Variance.* http://en.wikipedia.org/wiki/Analysis_of_variance (Acc. on Mar. 7th 2010)

Authorization and Disclaimer

Authors authorize LACCEI to publish the paper in the conference proceedings. Neither LACCEI nor the editors are responsible either for the content or for the implications of what is expressed in the paper.