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Influence of Recycled Concrete Aggregate and Crushed Clay Brick on Mechanical Properties of Concrete

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Abstract
Concrete is regarded as the most used construction material and natural aggregates used in concrete must be preserved by any acceptable means. This paper presents the results; compressive strength and tensile strength, of using Recycled Concrete Aggregate (RCA) and Crushed Clay Brick (CCB) as partial replacements for coarse and fine aggregates respectively in concrete. Three factors: RCA, CCB and CD were considered and combined at different levels of replacement in the determination of the compressive and tensile strength of concrete. The Response Surface Methodology (RSM) was used to determine the combination of these factors. RCA was used at 30%, 22.5% and 15% representing the high, middle and low replacement levels. Similarly, CCB was replaced at 20%, 15% and 10% which represents the high, middle, and low level respectively. CD was set to 28, 18 and 7 days representing the high, middle and low level. 20 combination set was generated using the RSM. It was found that RCA and CCB included concrete gains compressive strength faster within the first 7 days than the Normal Aggregate Concrete (NAC) but may not gain much more strength afterwards.
Keywords: Concrete, Recycled Concrete Aggregate, Crushed Clay Brick, Compressive Strength, Tensile Strength, Response Surface Methodology.

1.0 Introduction

In 2009, world annual concrete consumption was estimated at 20 billion ton per year. These figures are expected to constantly increase in the years to come. (P.K Metha, 2009). Due to the ever increasing demand for concrete, virgin aggregates are at the risk of becoming inadequate both in quality and quantity in the future. With about 75% of concrete being aggregate which are usually obtained from rocks, aggregates become more expensive every year due to increasing scarcity of the virgin aggregate. (American Concrete Pavement Association, 2010). In view of the scarcity and cost of the virgin aggregates in concrete production, efforts are now been made to preserve the near extinct virgin aggregates and provide some suitable substitute for them. The aforementioned situations will eventually lead to a point when the cost of concrete structures will become too expensive due to unavailability of raw aggregates. Many old buildings are being demolished annually due to urbanization and millions of tons of aggregates are generated. These aggregates are usually dumped in dump sites causing over-flow of canals and other irrigation systems. The high production of concrete also translates to the depletion of natural aggregate. With these environmental concerns in mind, the feasibility of using recycled construction waste and debris for the making of concrete needs to be examined. (Wong Kien Kuok, 2012)

Research showed that concrete produced with recycled aggregate had about 4% to 14% lower compressive strength compared to concrete made from natural occurring aggregate. (Frondistou-Yannas, S. 1997) Compressive strength of concrete produced with 50% RCA was found to be 11.26MPa and NCA was found to be 15.02MPa at 0.6 water-cement ratio. This shows a 26% reduction in compressive strength at 0.6 water cement ratio. (Y. V. Akbari et al 2011). At 0.6 water-cement ratio, the split tensile strength of RCA concrete specimen was found to be 5.24MPa, 4.98MPa, 4.53MPa and 3.87MPa. At 0.52 water-cement ratio, the split tensile strength was found to be 5.56MPa, 5.33MPa, 4.89MPa and 4.22MPa. At 0.43 water-cement ratio the split tensile strength was found to be 7.11MPa, 6.76MPa, 6.27MPa and 5.42MPa. The results were given in replacement order of 0%, 15%, 30% and 50%. (Y. V. Akbari et al 2011). The splitting tensile strengths of the various concrete specimens before 28 days decreased with an increase in the recycled aggregate content in all concrete mixes. (Shi-Cong Kou et al 2012)

Compressive strength test results for four different mixes at 7 days and 28 days from same w/c ratio were taken and recorded. It showed that natural coarse aggregate produced stronger concrete than RCA or/and CCB included concrete. It was observed that with increased CCB substitution levels, the compressive strength decreased. (Jian Yang et al 2011) At 28 days, there was a decrease in the compressive strength of concrete which was in the range of 10-35% for the crushed clay bricks aggregates concrete in comparison with an ordinary concrete. (Debieb, F. and Kenai, S. 2008) There was a reduction in the splitting tensile strength of crushed clay brick aggregate concretes which ranges between 11 and 26% with an average reduction of about 18.5%. Concretes produced with crushed clay brick aggregate seem to have a reduced splitting tensile strength of crushed clay brick aggregate concretes. (Osama M. Ghazi 2011)

This paper is focused on the mechanical properties of concrete which is produced from RCA as coarse aggregates and CCB as fine aggregates. The mechanical properties to be tested are the compressive strength and tensile strength. Recycled concrete aggregates (RCA) are produced from crushed concrete which are obtained from demolitions. Crushed clay bricks (CCB) are usually obtained from demolition of structures which were constructed with clay bricks.

2.0 Materials and Method

The cement used was Ordinary Portland Cement (OPC) conforming to the specifications of Type 1 OPC as given in BS 12. Coarse aggregate with maximum size of 20mm was used for this research and local river sand was used as normal fine aggregate. Both coarse and fine aggregates were substantially free from harmful chemical impurities. The RCA was obtained from crushed concrete; already cast concrete which *had no use* was collected and crushed to a maximum of size of 20mm in order to conform to the mix design to be adopted. The CCB was obtained from crushed clay bricks which were originally in the form of bricks. Manual crushing process was used to reduce the size of the aggregate to a size that could pass through the 1mm size of sieve. The concrete mix design was done in accordance with the standard published by the Building Research Establishment formerly known as Department of Environment. The standard is contained in "Design of Normal Concrete Mixes". Concrete grade 40 was used in the mix design and Table 1 below shows the result obtained from the concrete mix design for 1m^3 of concrete.

Figure 1: Crushed Clay brick

Figure 1: Recycled Concrete Aggregate

Table 1: Quantity of Materials for 1m^3 of Concrete

Material	kg/m^3
Water	205
Cement	445
Fine aggregate	717.5
Coarse aggregate	1032.5

The Minitab 16 software was used for the response surface methodology in this research in which the fine aggregate was replaced with CCB at 20% high level and 10% low level; coarse aggregate was replaced with RCA at 30% high level and 15% low level and the curing days (CD) for concrete is set to 7 and 28 days. These three variables have their high, medium and low level. Table 2 below shows the actual amount of materials to be used at high, middle and low level, the middle level was automatically generated using the Minitab Software.

Table 2: High, Medium and Low Level of Each Variable

CODE	Actual amount (kg)		
	CCB	RCA	CD
+1	0.7089 (20% Rep)	1.5320 (30% Rep)	28
0	0.5319 (15% Rep)	1.149 (22.5% Rep)	17.5
-1	0.3549 (10% Rep)	0.7660 (15% Rep)	7

**Rep: Replacement for each 0.004946m^3 of concrete.

Table 3 below shows the number of runs or batches that was cast and their respective combination in terms of level of replacement. Only the fine and coarse aggregate were replaced. All other materials remain constant through all batches.

Table 3: Codes and Actual Combination for Each Batch of Concrete

BatchNo	Code Combination			Actual Combination (Kg)				
	CCB	RCA	CD	FA	CA	CCB	RCA	CD
1	0	0	0	3.017	3.958	0.532	1.149	17.5
2	1	-1	-1	2.840	4.341	0.709	0.766	7
3	-1	-1	-1	3.194	4.341	0.355	0.766	7
4	1	1	1	2.840	3.575	0.709	1.532	28
5	0	0	0	3.017	3.958	0.532	1.149	17.5
6	1	0	0	2.840	3.958	0.709	1.149	17.5
7	0	0	-1	3.017	3.958	0.532	1.149	7
8	0	-1	0	3.017	4.341	0.532	0.766	17.5
9	1	-1	1	2.840	4.341	0.709	0.766	28
10	-1	-1	1	2.840	4.341	0.709	0.766	28
11	0	0	0	3.194	3.958	0.355	1.149	17.5
12	-1	1	1	3.194	3.575	0.355	1.532	28
13	-1	1	-1	3.194	3.575	0.355	1.532	7
14	0	0	0	3.017	3.958	0.532	1.149	17.5
15	1	1	-1	2.840	3.575	0.709	1.532	7
16	0	0	0	3.017	3.958	0.532	1.149	17.5
17	-1	0	0	3.194	3.958	0.355	1.149	17.5
18	0	0	0	3.017	3.958	0.532	1.149	17.5
19	0	0	1	3.017	3.958	0.532	1.149	28
20	0	1	0	3.017	3.575	0.532	1.532	17.5

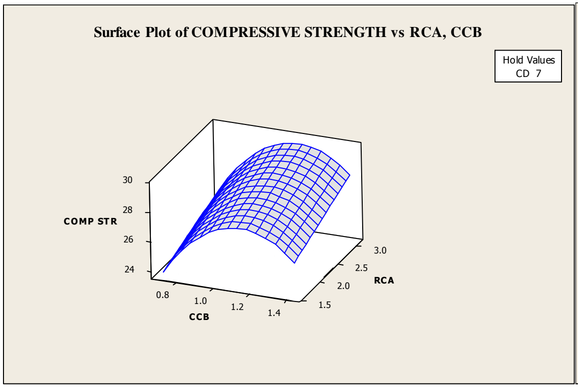
The batching was done using the parameters obtained from the mix design. Mixing of the concrete followed the batching; a mechanically operated concrete mixer was used. Placing and Compaction were done according to the specifications in BS EN 12350 PART 6 2000. De-molding was done 24 hours after the concrete was cast. The concrete was finally set and was cured in clean water at room temperature for a number of days appropriate with the each batch. The concrete cubes of dimensions $150mm \times 150mm \times 150mm$ were tested for compressive strength at 7, 18 and 28 days according to the category which the concrete mix belongs and this was done in accordance with the procedure stipulated in BS EN 12390-3 2009. Cylindrical shaped concrete specimens of size 100mm diameter and 200mm length were used for the tensile splitting strength according to BS EN 12390-6 2000.

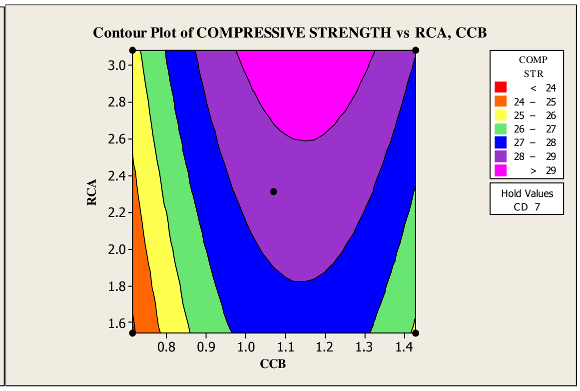
3.0 Result and Discussion

The compressive strength of concrete specimen ranges from 24.22N/mm^2 to 27.78N/mm^2, 27.95N/mm^2 to 37.2N/mm^2 and from 25.15N/mm^2 to 32.48N/mm^2 at 7, 18 and 28 days respectively. No concrete specimen had a compressive strength equal to the grade of concrete used in the mix design. However, batch with code "1,0,0" attained a compressive strength of 37.2N/mm^2 at 18 days which is the closest to grade used in the mixed design. The tensile strength results ranges from 1.42N/mm^2 to 2.41N/mm^2, 2.9N/mm^2 to 3.78N/mm^2 and from 1.96N/mm^2 to 2.93N/mm^2 at 7, 18 and 28 days respectively.

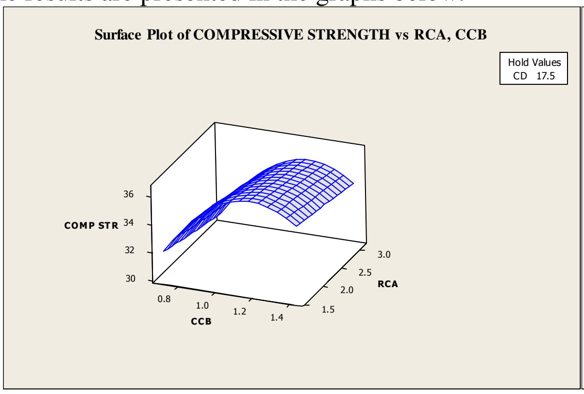
3.1 Compressive Strength

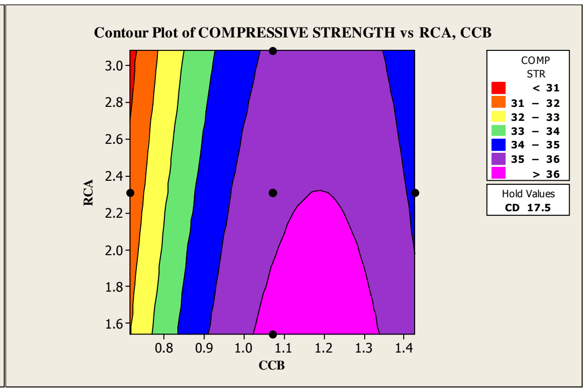
For the compressive result at 7 days, only the concrete which has the CD at low level i.e. at "-1" were tested. The results are presented in the graphs below.



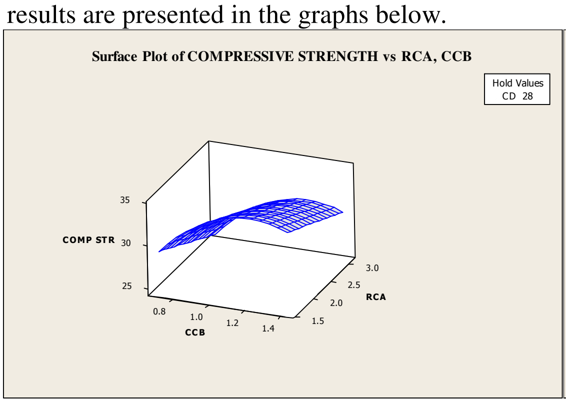


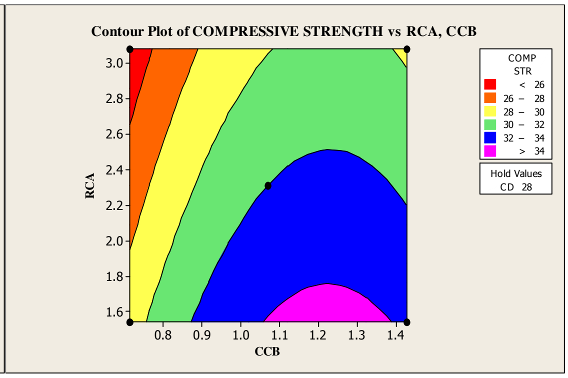
For the compressive result at 18 days, only the concrete which has the CD at low level i.e. at "0" were tested. The results are presented in the graphs below.





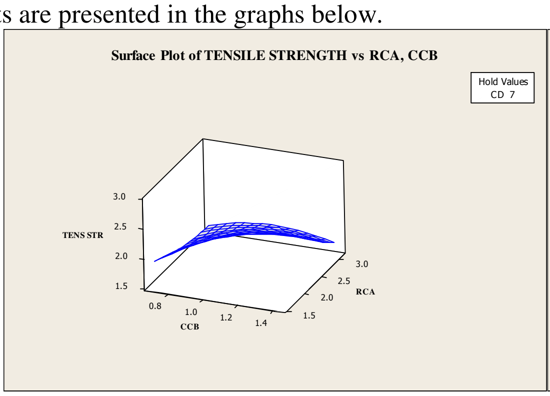
For the compressive result at 28 days, only the concrete which has the CD at low level i.e. at "1" were tested. The results are presented in the graphs below.

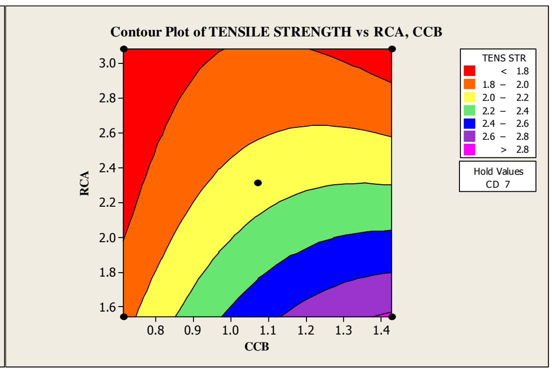




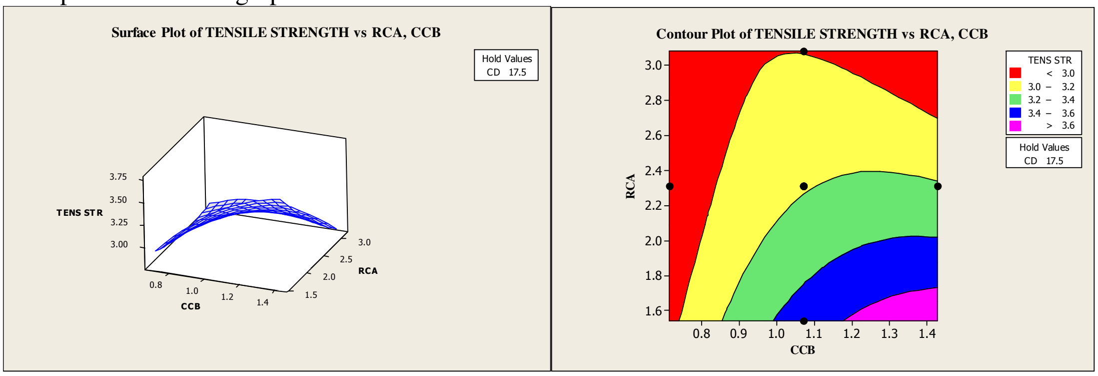
3.2 Tensile Strength

For the tensile result at 7 days, only the concrete which has the CD at low level i.e. at "-1" were tested. The results are presented in the graphs below.

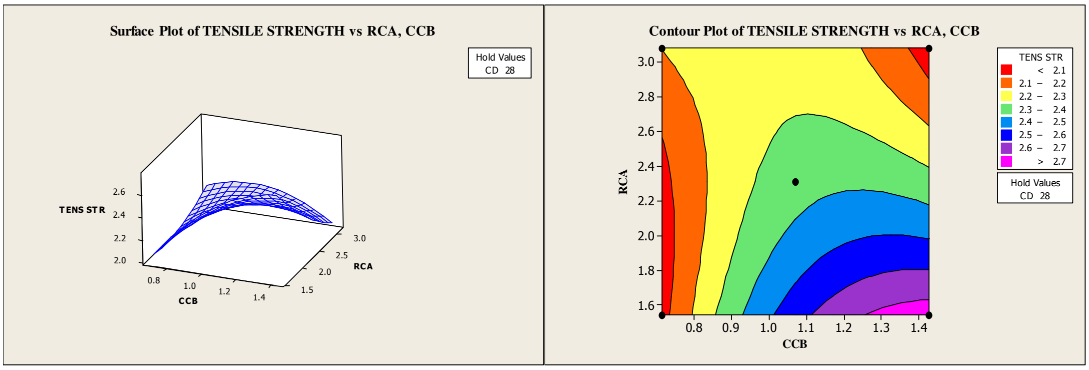




For the tensile result at 18 days, only the concrete which has the CD at low level i.e. at "0" were tested. The results are presented in the graphs below.



For the tensile result at 28 days, only the concrete which has the CD at low level i.e. at "1" were tested. The results are presented in the graphs below.



4.0 Conclusions

Concretes made from RCA and CCB gains compressive strength faster than the normal aggregate concrete within the first 7 days of curing. At 18 and 28 days however, the rate at which the RCA and CCB included concretes gains its compressive strength is much slower than the NAC. As seen from the results, concretes made from RCA and CCB will only experience little or no increase in compressive strength after 7days.As seen from the 7 days compressive strength of the concrete specimen, the higher the amount of RCA, the lower the compressive strength of concrete. Within the context of this research, the compressive strength of concrete made from CCB concrete will be at a maximum when the CCB content kept between 15% and 20%. The tensile strength of concrete made from RCA and CCB will rise from a minimum value to about its peak from 7 days until 18 days, the tensile strength will however depreciate at 28 days. RCA demonstrates to be weaker in its contribution to the tensile strength of concrete as compared to the effect of CCB in concrete. NAC produced a higher tensile strength than the RCA and CCB included concrete at each curing day. The density of the RCA and CCB included concrete at any age are relatively close to that of the NAC

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