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Optimal Performance of Compressive Strength of Recycled Aggregate Concrete with Cement Content 350kg/m^3 400kg/m^3 and 450kg/m^3

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ABSTRACT
Theuse of recycled concrete aggregates (RCA) has been an important discuss in many engineering fora. In this study high strength concrete is developed using RCAto replace natural aggregates and nano-metakaolin (NMK) as partial replacement for cement usingthree binder(cement) content of 450kg/m3, 400kg/m3, and 350kg/m3 at water/cement ratios of 0.22, 0.25 and 0.28, respectively. Experiments were conducted to determine the compressive strengths of the concrete at 5%, 7.5% and 10% replacement of the binder and aggregates simultaneously. Results showed that usinga mix design ratio of 1:1.71:2.57, a high strength concrete using NMK and RCA at 10% replacement for cement and natural aggregates can be produced. The replacement of cement and natural aggregate with NMK and RCA at 10% can produce a high strength concrete with water cement ratio 0.22, 0.25 and 0.28 for 450kg/m^3 and 400kg/m^3 binder content. For 350kg/m^3 binder content,high strength concrete can only be achieved at 28days with 0.25 water cement ratio.

Keywords: *Recycled Concrete Aggregate (RCA), Nano-metakaolin (NMK), Compressive Strength, Non-Linear Regression.*

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I. Introduction

Due to its flexibility, concrete is the most common construction material used worldwide.The population growth has resulted in a significant increase in the demand for concrete.This has led to an increase in demand for the elements that make up concrete, particularly aggregate, which makes up around 70–80% of the entire volume of concrete(Neville, 1995).According to Yebia (2015), the global use of concrete aggregate by the construction sector in 2015 was 48.4 billion metric tons, with an average annual growth rate of roughly 5%.It is evident that there may be a severe shortage of concrete given the strong demand for natural (virgin) aggregate.Environmental risks also result from over investigation of virgin aggregate materials.The investigation of an alternative has become necessary due to the two aforementionedconsiderations.

One of the best options for a sustainable concrete mixture is the use of recycled concrete aggregate (RCA).The adoption of RCA has accelerated infrastructure development while addressing issues with environmental contamination, a lack of natural resources, and landfills.According to Lu, (2009), China's structural and pavement infrastructures have effectively utilized RA made from building demolition wastes.The period between the introduction of RCA use was after World War II, according to Buck (1977), this period was marked by an excessive amount of building and road demolition as well as a pressing need to both dispose of the leftover debris and rebuilding of Europe.The use of RCA decreased after the urgent necessity to recycle concrete.The United States started using RCA again in the 1970s for non-structural purposes such fill material, foundations, and base course material.Since then,studies have been done to determine how practical RCA is as a replacement for underutilizednatural aggregate (NA) in structural concrete.However, the applications of RCA are constrained by a noticeable decline in strength and durability characteristics.Hoffmann *et al.* (2012) noticed differences between the qualities of RCA-made concrete and conventional concrete, which they attributed to the significant degree of variation in aggregate composition.

The removed concrete from old buildings is frequently deemed useless and thrownaway as demolition debris.RCA is made by gathering leftover concrete and chopping it up.The coarse RCA, or the coarse aggregate from the original concrete that is produced when the mortar is separated from the rock that is reused, is the subject of this study. Also, nano-metakaolin (NMK) is introduced in this study as a partial replacement for cement knowing the cost of Portland cement and its environmental concerns.

II. Materials and Methods

2.1. Materials

The materials used in this study were sampled in accordance to BSEN 932 Part 2(1997). They include: Recycled Concrete Aggregates(≤10mm maximum size), Natural Granite Aggregates of maximum size (≤10mm), Ordinary Portland Cement, Natural River Sand (fine aggregates) of 5mm maximum size conforming to BS 882:(1992), Nano-Metakaolin conforming to (EN 934-2), Potable water conforming to BS3148 (1970), Konkreto SP 430 superplasticizer manufactured by PureChemManufacturer Ltd was used.

2.2. Methods

In this study, the Department of Environment'sMix Design Procedure for concretes (DOE) was adopted.However, the cement content was already chosen for 450kg/m^3, 400kg/m^3, 350kg/m^3 respectively. Also, the water content (w/c) ratio of 0.22, 0.25, and 0.28 wasadopted to determine the target strength based on the curing age, using the empirical relationship below developed by Lydon (2002) to compute the target compressive strength at a specified water/cement ratio.

$$f_c = \frac{140.44}{(10.92)^{w/c}} \tag{1}$$

To obtain the water content value for each water cement ratio, the relationship as stated in Equation 2 was used.

$$\frac{w}{c} = 0.22 \tag{2}$$

The water content for the respective water cement ratios was gotten using this method. Nine different concrete mix designs were prepared for cement content at 450kg/m^3, 400kg/m^3, 350kg/m^3, and water cement ratio 0.22, 0.25, and 0.28 respectively. In this study, the RCA and NMK were used to replace the natural coarse aggregates and cement at 5%, 7.5%, and 10% by weight respectively.The mix design ratio adopted for the control was 1:1.71:2.57. Also, Konkreto SP 430superplasticizer manufactured by PureChemwas added to each mix. The weight of the superplasticizer was 1.2% of the cement content.

III. Results and Discussions

The results of the compressive strength for the three-cement content adopted for this study are presented in Tables 1, 2 and 3.

Table 1. Average Compressive Strength Results for 450kg/m^{3}Cement Content

		% Modification of Cement and RCA			
W/C	Curing Days	0%	5%	7.5%	10%
	3	36.44	34.66	33.70	28.71
	7	39.25	37.33	35.70	32.30
	14	50.34	43.55	40.00	37.33
0.22	28	66.44	60.88	58.37	56.00
	3	39.55	39.11	36.3	31.86
	7	42.66	41.03	38.81	35.25
	14	55.60	47.40	43.11	40.44
0.25	28	69.33	62.59	60.88	58.51
	3	36.29	34.66	31.25	27.55
	7	41.03	40.7	37.48	36.15
	14	49.11	45.77	42.07	37.33
0.28	28	64.44	59.77	57.55	55.55

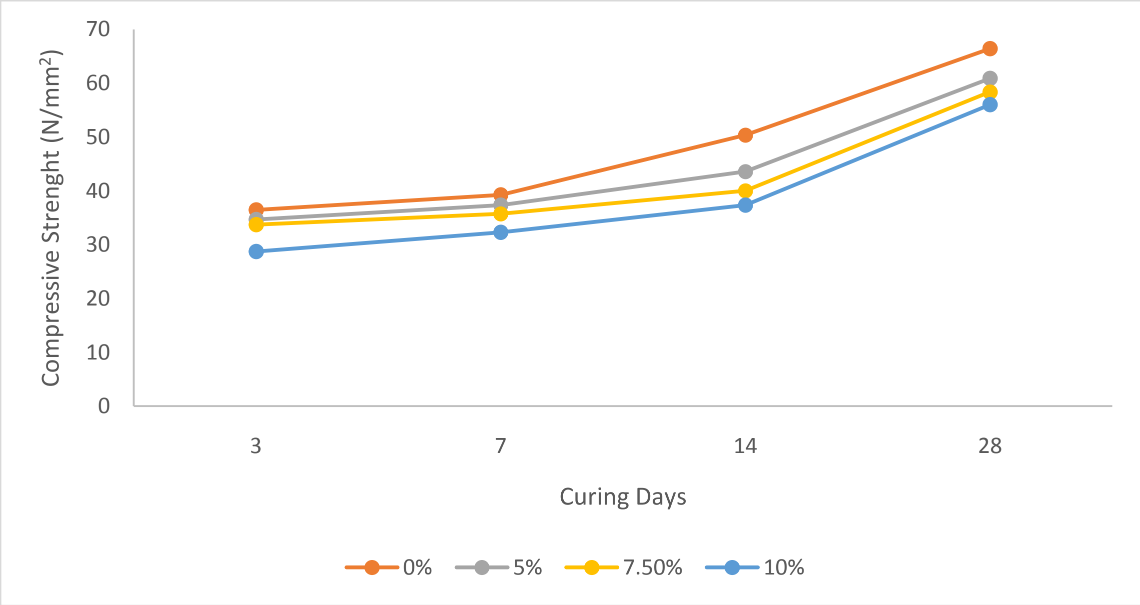

Figure 1. Compressive Strength against Curing days for 0.22 w/c ratio for 450kg/m^3 Cement Content

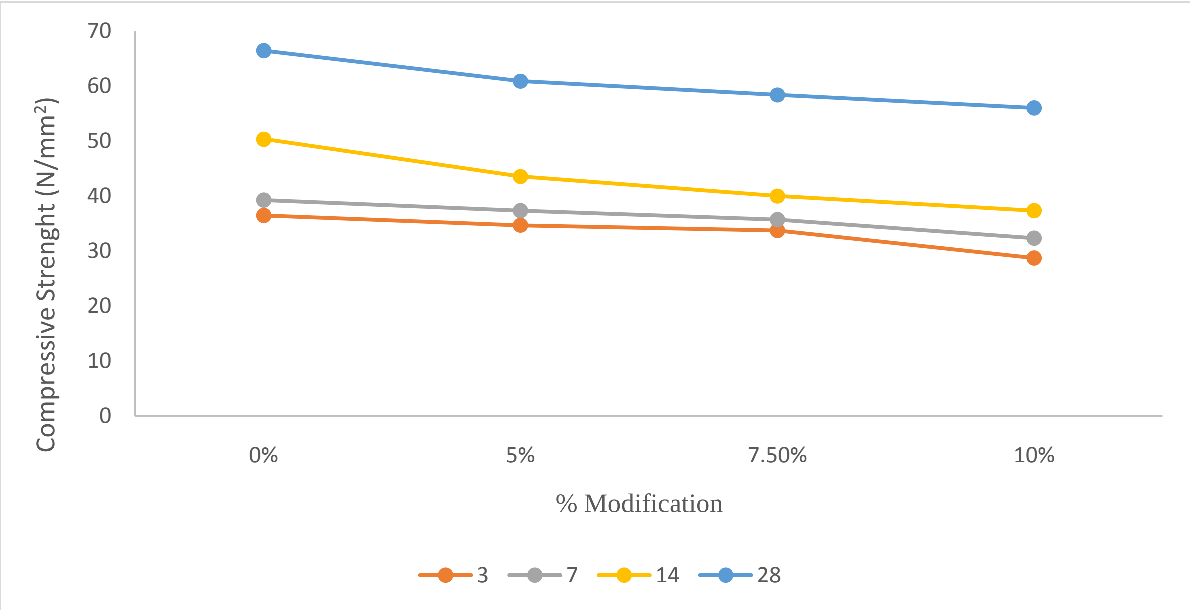

Figure 2. Compressive Strength against % Modifications for 0.22 w/c ratio for 450kg/m^3 Cement Content

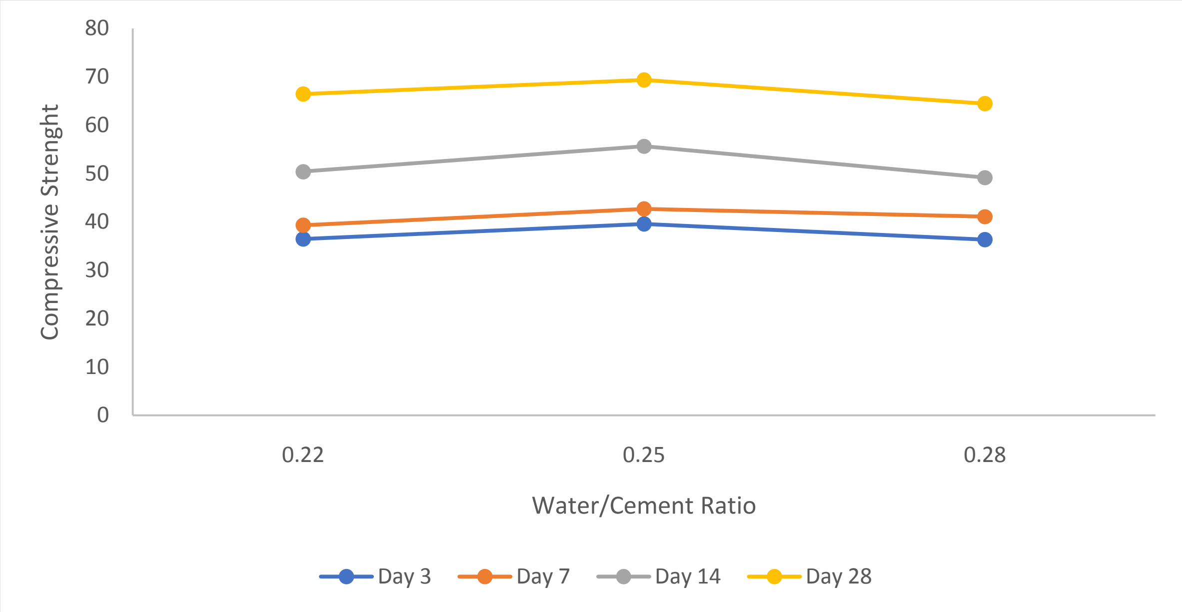

Figure 3. Compressive Strength against w/c ratio for 450kg/m³ Cement Content at 0% modification

Table 2. Average Compressive Strength Results for 400kg/m³ Cement Content

		% Modification of Cement and RCA			
W/C	Curing Days	0%	5%	7.5%	10%
	3	34.37	33.18	28.74	27.55
	7	38.22	37.03	34.48	33.77
	14	48.50	43.25	38.81	35.55
0.22	28	63.77	58.66	56.66	54.22
	3	37.33	35.50	33.18	28.44
	7	40.58	39.68	36.14	34.07
	14	51.37	44.00	41.03	39.11
0.25	28	65.33	60.00	58.00	55.77
	3	31.40	29.33	28.14	25.77
	7	36.44	35.50	33.18	31.55
	14	46.81	42.11	37.70	34.96
0.28	28	61.77	57.33	55.11	53.33

Table 3. Average Compressive Strength Results for 350kg/m³ Cement Content

		% Modification of Cement and RCA			
W/C	Curing Days	0%	5%	7.5%	10%
	3	30.66	30.22	28.00	26.81
	7	34.66	33.77	31.85	29.62
	14	44.62	38.66	35.7	34.81
0.22	28	60.00	55.00	52.14	48.29
	3	33.92	32.44	31.55	28.74
	7	37.63	35.55	33.77	31.40
	14	48.65	40.44	37.77	35.85
0.25	28	62.22	57.77	53.33	50.66
	3	30.37	29.48	27.70	24.88
0.28	7	34.51	33.48	31.55	28.44

14	43.77	37.92	35.11	34.51
28	58.22	53.33	50.14	46.22

In Table 1 shown above for 450kg/m^3 binder content, the compressive strength was observed to be increasing as the number of curing days increases. This is shown in Figure 1. The increase in compressive strength from day 3 to 28days is 81.56%, 71.68% and 83.95% on the average respectively at 0.22, 0.25 and 0.28 water cement ratio. The results presented in Figure 2 have shown that an increase in percentage replacement of the binder and natural aggregates using NMK and RCA, reduces the strength. However, at 10% replacement the strength is within acceptable limit for high strength concrete at 28days for the different water cement ratios. Also, as the water cement ratio increases from 0.22 to 0.25, the compressive strength increased but reduced as the water cement ratio increased to 0.28 (See Figure 3).

The results for 400kg/m^{3}and 350kg/m^{3}binder content are presented in Table 2 and Table 3. The results showed similar behavior. However, the average percentage increase for 400kg/m^{3}binder content was 89.08%, 78.73% and 98.74% respectively at 0.22, 0.25 and 0.28 water cement ratio. While the average percentage increase for 350kg/m^3 binder content was 86.00%, 76.71% and 84.85% respectively at 0.22, 0.25 and 0.28 water cement ratio. It is important to note that the compressive strength at 10% replacement at 28days for 400kg/m^3 binder content met the requirements for high strength concrete for all the water cement ratios but that of 350kg/m^3 binder content was okey at 0.25 water cement ratio only. This is because high strength concretes are concretes with a minimum grade of 50N/mm^2 or 50Mpa.

IV. Conclusion

The conclusion of this study is based on the set aim and objective and it is summarized as follows:

1. The mix design ratio of 1:1.71:2.57 is ideal to produce a high strength concrete using NMK and RCA at 10% replacement for cement and natural aggregates.
2. The replacement of cement and natural aggregate with NMK and RCA at 10% can produce a high strength concrete with water cement ratio 0.22, 0.25 and 0.28 for450kg/m^3 and 400kg/m^{3}binder content
3. For 350kg/m^3 binder content high strength concrete can only be achieved at 28days with 0.25 water cement ratio.

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