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EFFECT OF COARSE AGGREGATE SIZE AND WATER CEMENT RATIO ON STRENGTH OF STRUCTURAL CONCRETE AND ITS OPTIMAL VALIDATION

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Abstract–Concrete is the most widely used construction/infrastructural materials due to its versatility. In practice, availability of aggregate size for specific concrete mix has been a major concern to some contractor/engineers leading to use of available size of aggregate. Based on this, this study investigated the effect of coarse aggregate on compressive strength of structural concrete with varying water cement ratio. Coarse aggregate (crushed stone) of 10, 15, and 20 mm maximum sizes were used. A mix ratio of 1:2:4 was adopted using cement content of 275kg/m^3 with w/c of 0.5, 0.6, and 0.7. Total number of eighty-one (81) concrete cubes (150 by 150 by 150 mm) were cast and cure in water by immersion for 7, 14, and 28 days. The results of the compressive strengths reduced as the coarse aggregate increased from 10 to 20 mm. Similarly, as the water cement ratios increased at each curing age, the compressive strengths witnessed consistent decreased in strength. The highest compressive strength was obtained at water cement ratio of 0.5 while the least was obtained at water cement ratio of 0.7 for all sizes of coarse aggregate used. The study concluded that adoption of 0.5 water cement ratio using 10 and 15 mm coarse aggregate would produce concrete of better strength than concrete produce with 20 mm coarse aggregate.

Keywords: Aggregate, Compressive Strength, Concrete, Water Cement Ratios, Validation

1. Introduction

Concrete is a composite material which is made up of filler and a binder (Chudley and Greeno, 2006; Adebara *et al.,* 2016; Adeyemi *et al.,* 2017; Ige *et al.,* 2017; Anifowose *et al.,* 2018; Adedokun *et al.,* 2019; Odeyemi *et al.,* 2021). It is usually formed by mixing binder (either cement, supplementary cementing materials or combination of both) water, fine aggregate and coarse aggregate. The fine and Coarse Aggregates (CA) account for 75% of concrete volume and aggregates play an important role in properties of concrete. (Odeyemi *et al.,* 2015; Anifowose *et al.,* 2017; Ige *et al.,* 2018; Anifowose *et al.,* 2019; Adeyemi *et al.,* 2019; Odeyemi *et al.,* 2023).

Aggregate properties do influence concrete properties, but by and large they do not control the performance of the concrete. The essential requirement is that the aggregate remains stable within the concrete in its exposure conditions. There are three main reasons for mixing aggregate with cement paste to form concrete, rather than using cement paste alone. The first and oldest reason is that aggregate is cheaper than cement, so its use extends the mix and reduces costs. Second, aggregate reduces shrinkage and creep, giving better volume stability. Third, aggregate gives greater durability to concrete. Many deterioration processes principally affect the cement paste (Newman and Choo, 2003; Zongjin, 2011; Neville, 2011).

Abdullahi (2012) examined the effects of aggregate type on compressive strength of concrete. The opined that aggregate size has effect on the compressive strength of concrete and concrete made from crushed quartzite has higher compressive strength at all curing ages compared to the concrete with granite. However, in the study of Aginam *et al.,* (2013), the compressive strength of normal concrete with granite as a CA was higher than concrete made with washed and unwashed gravel as a coarse aggregate.

Xie *et al.,* (2012) also opined that compressive strength of concrete decreases with increase in CA size, up to a critical volume of aggregate, and then decreases. The initial increase in strength witnessed in the study was due to a reduction in the volume of voids with the addition of aggregate.

In Nigeria, availability of aggregate size for specific concrete mix has been a major concern to some Contractor/Engineers leading to use of available aggregate size. In addition to the problem associate with aggregate size, use of water cement ratio is also a concern and in most cases, consideration of volume of water needed during concrete mix are neglected. These has been practices (negligence of water cement ratio) and challenges (use of available aggregate size) witnessed by some engineers on site. This calls for effect of CA sizes with varying water cement ratio (w/c) for concrete production.

2. Materials and Methods

The materials used in this study includes: Ordinary Portland cement of Grade 32.5R of (Dangote brand); Water; Fine and CA.

CA (crushed stone) of 10, 15, and 20 mm maximum sizes were used. A mix ratio of 1:2:4 was adopted using cement content of 275kg/m^3 in accordance with Table C-1 of BS8500:1 (2006) with w/c of 0.5, 0.6, and 0.7. Particle size distribution was carried out on fine aggregate in accordance with BS EN 933-1 (2012), to determined fineness modulus and coefficient of uniformity. Compacting factor and slump test were carried out on fresh concrete in accordance with BS EN 12350:4 (2009) and BS EN 12350:2 (2009), respectively. Total number of eighty-one (81) concrete cubes (27 cubes each for 10, 15 and 20 mm CA) of 150 by 150 by 150 mm were cast and cure in water by immersion for 7, 14, and 28 days. Density and compressive strength tests were conducted on hardened concrete in accordance to BS EN 12390:7 (2009) and BS EN 12390:3 (2009), respectively. The results of the concrete strengths were validated through Response Surface Method (RSM) based on historical data design using Design-Expert 7.0 version. The concrete mix proportions (for nine specimens) presented in Table 1 was adopted for concrete production with 10, 15 and 20 mm aggregate size.

Table 1: Concrete mix proportion (1:2:4)

W/C	Water (kg)	Cement (kg)	Fine Aggregate (kg)	Granite (kg)
0.5	5.48	10.95	21.90	43.80
0.6	6.57	10.95	21.90	43.80
0.7	7.67	10.95	21.90	43.80

3. Results and Discussion

3.1 Particle size distribution of fine aggregate

The particle size distribution result is as presented in Figure 1. The Fineness Modulus (FM) obtained was 2.89 which meet the acceptable limits by ACI (2007). The Coefficient of uniformity (Cu) of the fine aggregate used as obtained from Figure 1 was 2.88 (< 4.0). This is an indication that the Cu of the fine aggregate is uniformly graded and gives a good workability in the fresh concrete (Shetty, 2000; Neville, 2011).

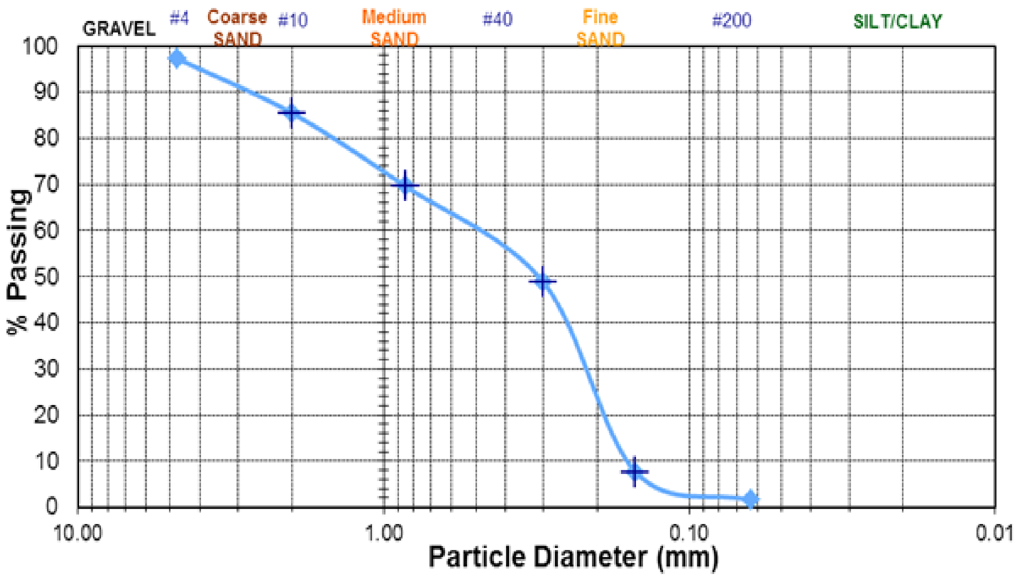

Figure 1: Particle size distribution curve of fine aggregate

3.2 Slump and compacting factor of the fresh concrete

The results of the fresh concrete (slump and compacting factor) is as presented in Figures 2 and 3.

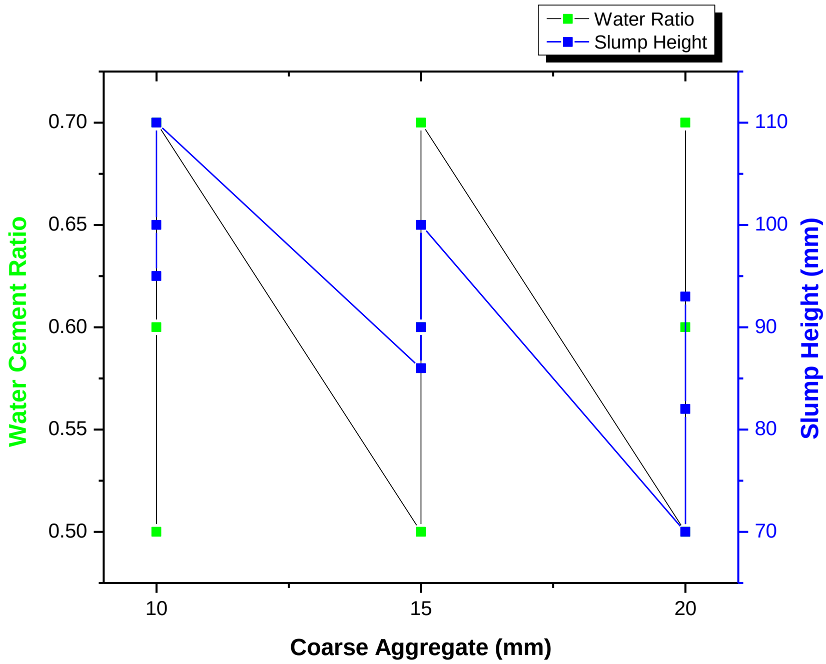

Figure 2: Effect of CA and w/c on concrete slump

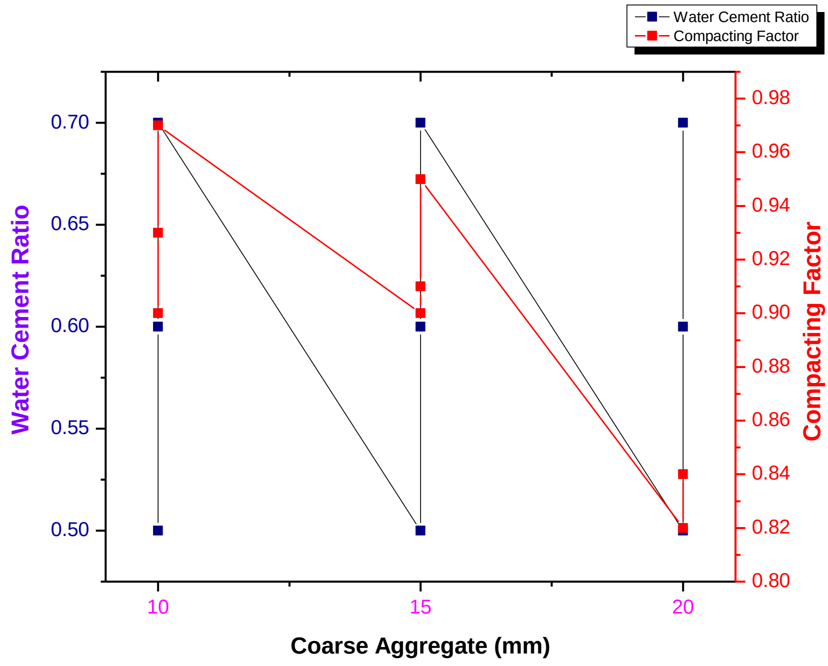

Figure 3: Effect of CA and w/c on compacting factor

True slump was exhibited by the fresh concrete mix. The slump height values increased as the w/c increases. However, the slump height witnessed reduction as the CA size increases from 10 to 20 mm (Figure 2). The concrete became more workable as the w/c increases. The corresponding compacting factors (Figure 3) shows similar trends to the slump behaviour and the values of the compacting factors are within the range of 0.70 to 0.98 specified by BS EN 12350:4 (2009).

3.3 Density of hardened concrete

The density results of the hardened concrete cubes for the aggregate sizes (10 – 20 mm) with varying water cement ratio (0.5 – 0.7) are as presented in Table 2.

Table 2: Summary of Mean Density of Concrete Cubes

Curing Age	**Mean Density of Concrete Cubes (kg/m^3)**								
	10 mm			**15 mm**			**20 mm**		
	0.5	**0.6**	**0.7**	**0.5**	**0.6**	**0.7**	**0.5**	**0.6**	**0.7**
7	2420	2420	2400	2400	2370	2340	2410	2350	2350
14	2468	2460	2440	2370	2400	2390	2380	2380	2400
28	2518	2515	2515	2515	2490	2494	2450	2450	2400

All concrete cubes produced ranged from 2350 kg/m^3 – 2518 kg/m^3. The results meet the recommended range of 2000 kg/m^3 – 2600 kg/m^3 for normal structural concrete (BS EN 206 (2013; Anifowose *et al.*, 2021; Odeyemi *et al.*, 2020; Salaudeen and Anifowose, 2022).

3.4 Compressive strength of hardened concrete

The results of the compressive strength of hardened concrete cubes for the CA (10 – 20 mm) with varying water cement ratio (0.5 – 0.7) are as presented in Figures 4 to 6.

The compressive strength results of 10 mm aggregate size at 0.5 and 0.6 w/c conforms to specified value of 20 N/mm^2 at 28 days curing for grade 20 concrete as contained in BS8110:2 (1985) while strength of 0.7 w/c is above required strength of 15 N/mm^2 for concrete grade 15 at 28 days. The strengths of 15 and 20 mm CA at 0.5 w/c also conforms to specified value of 20 N/mm^2 at 28 days curing for grade 20 concrete as contained in BS8110:2 (1985) while strength of 0.6 and 0.7 w/c were above required strength of 15 N/mm^2 for concrete grade 15 at 28 days. The results indicated that the compressive strengths reduced as the CA increased from 10 to 20 mm (Figures 4 to 6). Similarly, as the w/c increased at each curing age (7, 14 and 28 days), the compressive strengths witnessed consistent decreased in strength. Concrete with low w/c provides better bonding between cement paste and aggregates (fine and CA). Thereby improving characteristics strengths of hardened concrete (Neville, 2011; Varma, 2015; Adedokun *et al.,* 2021; Anifowose *et al.,* 2021).

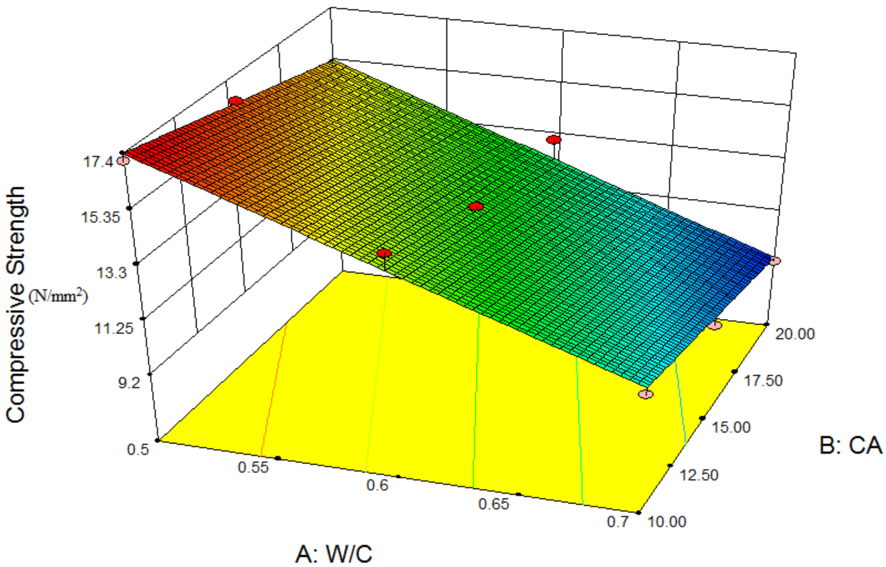

Figure 4: Effect of CA and w/c at 7 days curing

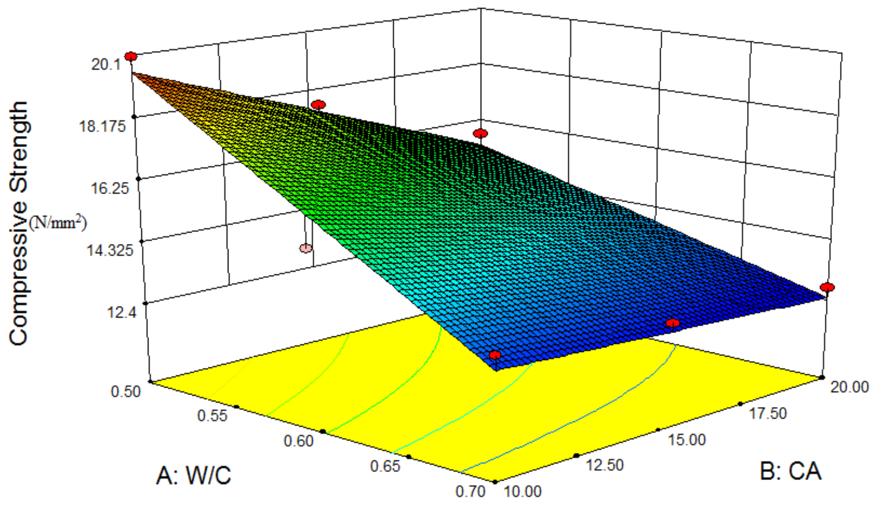

Figure 5: Effect of CA and w/c at 14 days curing

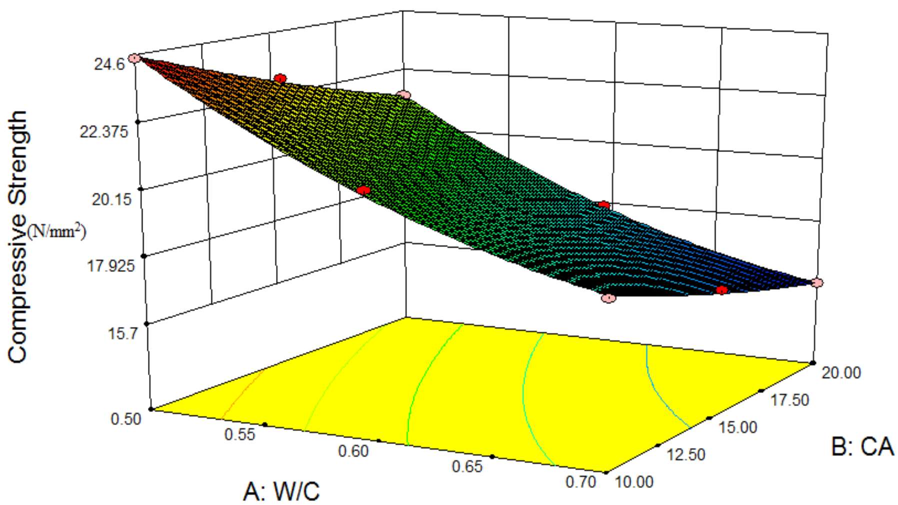

Figure 6: Effect of CA and w/c at 28 days curing

4. Result Validation

The relationship between the predicted versus experimented values (Figure 7) of the compressive strength at 28 days were optimized using design expert software (version 7.0). The model *F* value of the experiment is 376.05 which is significant with *p* (0.0002) < 0.05. The Predicted R-Squared (0.9871) is in reasonable agreement with the Adjusted R-Squared (0.9958). The "Adequate Precision" ratio of 57.325 is higher than 4, which is desirable for the model and indicates an adequate signal (Ogunleye *et al.*, 2018; Adedokun *et al.*, 2021; Adedokun and Anifowose, 2022).

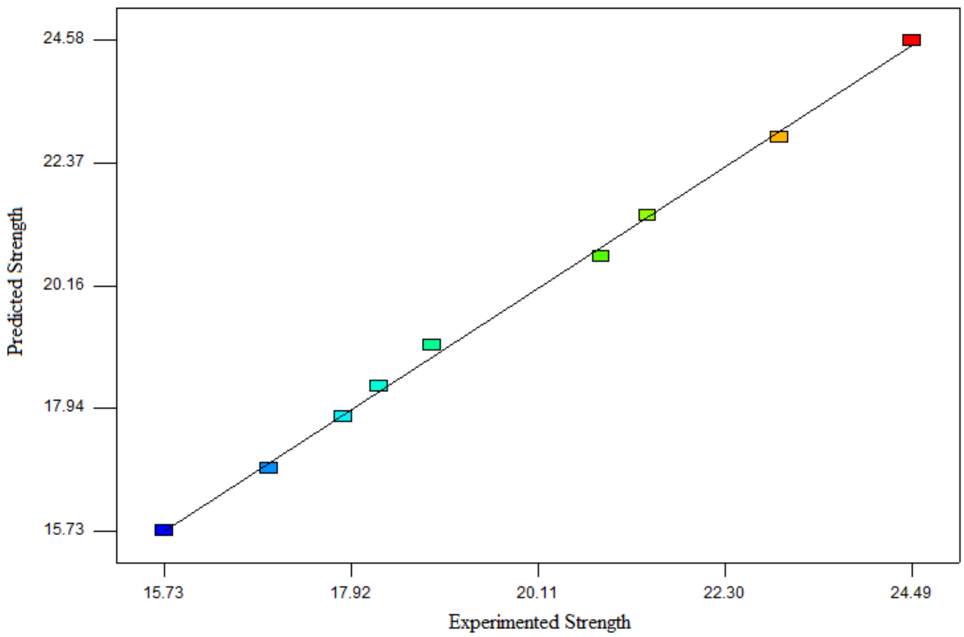

Figure 7: Predicted strength versus experimented strength at 28 days

The optimal plot for the response variables is presented in Figure 8. A desirability of 1.000 with a maximum response value of 24.535 N/mm^2 was obtained at A (W/C) = 0.5 and B (CA) = 10.03 mm.

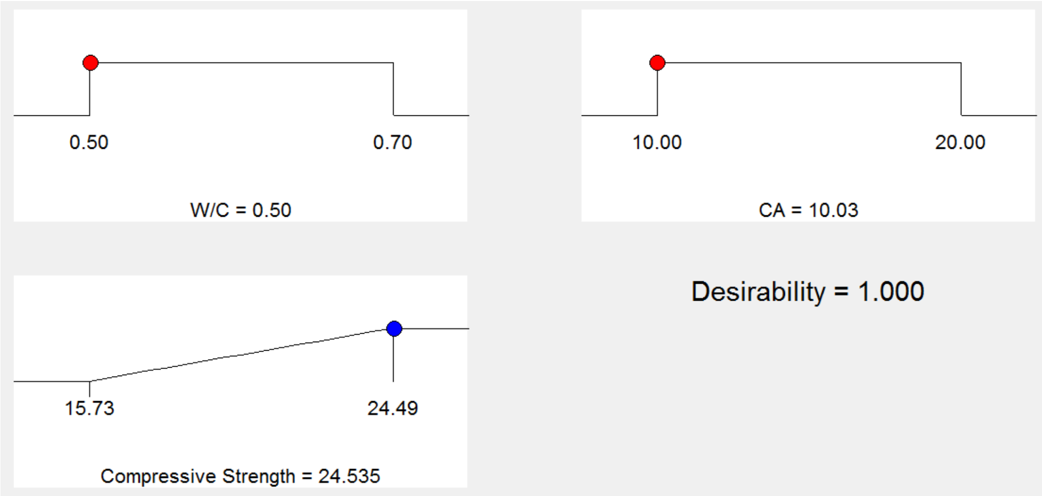

Figure 8: Optimal compressive strength of hardened concrete

5. Conclusion

The effect of CA sizes on the compressive strength of structural concrete with varying w/c was investigated. From the study, the slump height values of the fresh concrete increased as w/c increases. However, the slump height witnessed reduction as the CA size increases from 10 to 20 mm. The corresponding compacting factors shows similar trends to the slump behaviour. The compressive strength results reduced as the CA increased from 10 to 20 mm. Similarly, as the w/c increased at each curing age (7, 14 and 28 days), the compressive strengths witnessed consistent decreased in strength. The highest compressive strength was obtained at w/c of 0.5 while the least was obtained at w/c of 0.7 for the three CA used. However, 10 mm CA produced maximum compressive strength while 20 mm produced the least strength. Adoption of 0.5 w/c using 10 and 15 mm CA would produce concrete of better strength than concrete produce with 20 mm CA.

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