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Effects of Concrete Grades on Strength Characteristics of Reinforced Concrete Slender Beams

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ABSTRACT: This paper presents the results of experimental study on the effects of concrete grades on strength characteristics of reinforced concrete slender beams. The materials used for the concrete were sand, crushed granite, stone dust, cement and water. Concrete mix ratios of 1:2:4 and 1:3:6 by weight with water-cement ratio of 0.6 was used. Four (4) reinforced concrete slender beams were cast, which were loaded with a point load at the beam centre. The results of the work show that, with decrease in concrete grade, there was corresponding decrease in ultimate load and shear capacity. For a drop of 16.67%, 38.67% and 62% in concrete grade there were corresponding decrease in the strength characteristics of beams by about 10.5%, 21.79% and 32.75% respectively. Therefore, decrease in concrete grade does not have the same percentage decrease in the strength characteristics of beams. Also, the mode of failure of reinforced concrete beams, depends not only on the ratio of the span to height of beam and the percentage area of reinforcement provided, but also on the concrete grade.

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Concrete is one of the major construction material being used worldwide. Its great advantage is that as a man-made material, it can be poured into moulds of any shape where it sets, thus removing the necessity to form the material by carving, as is the case with stone. A further advantage is that its properties may be tailored to a considerable degree to meet different situations, (Olanitori and Olotuah 2005). As from 1970's, considerable improvement has taken place in the understanding of structural concrete and has been incorporated in the revised codes of practice. The British Standard CP110 (1972), has superseded the British Standard Codes of Practice CP114 (1957), for reinforced concrete. Similarly, in America the ACI Standard ACI 318-71 (1971) has replaced the previous standard ACI 318-63 (1963). The major aspects of the revised codes is the limit state approach for designing reinforced concrete structures and the separation of methods of concrete mix design procedures from that of concrete design considerations (Olanitori, 2013). The basic ingredients of concrete are: gravel (usually stone in the range of 5-20 mm), sand, cement and water. The cement is the only industrially produced ingredient and is used in relatively small quantities compared with the sand and gravel (typically about 15% by weight of the concrete). This makes concrete a cheap construction material compared with steel Narayanan and Beely (2001). However, the quality of concrete produced depends on the quality of its constituent materials and their mix ratios; the higher the percentage of clay/silt content of sand, the lower the characteristic strength (Olanitori and Olotuah , 2005). Olanitori L.M. (2012), determined the cost implication of mitigating the effect of clay/silt content of sand using mathematical models. There is strong evidence that aggregate type is a factor in the strength of concrete. Ezeldin and Aitcin (1991) compared concretes with the same mix proportions containing four different coarse aggregate types. They concluded that, in high-strength concretes, higher strength coarse aggregates typically yield higher compressive strengths, while in normal-strength concretes, coarse aggregate strength has little effect on compressive strength. Other research has compared the effects of limestone and basalt on the compressive strength of high-strength concrete, Giaccio *et al.* (1992). Tests by Zhou *et al.* (1995) show that compressive strength increases with an increase in coarse aggregate size. However, most other studies disagree.

Pawar *et al* (2016), studied the effects of gradation of aggregates on properties of concrete and concluded that fine aggregate gradation has more detrimental effect on concrete properties than coarse aggregate gradations. In their work, Albarwary *et al* (2017), on

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the effect of aggregate maximum size upon compressive strength of concrete, concluded that, in general the compressive strength of concrete increases when the maximum size of aggregate decreases and the maximum aggregate size strongly influences the concrete strength. Also, the test results also show that the optimum concrete strength is reached by using aggregates of 9.5mm maximum size. Petrounias *et al* (2018) deduced from their study that, mineralogy and microstructure of the coarse aggregates affected the final strength of the concrete specimens. Tunio *et al* (2019) noted that coarse aggregate gradation, cement-aggregate proportion and w/c ratio significantly affect the compressive strength of no fines concrete. Reinforced concrete beams can fail by bending, by shearing or by flexural-shearing mode of failures. Olanitori and Afolayan (2014) noted that, most reinforced concrete structures failed by shearing, and this is because there exist discrepancies between estimated shear capacity based on equations from the codes and, the actual shear capacity and concluded that more research work should be conducted on models that can predict the shear capacity of reinforced concrete beams more accurately. Olanitori and Olotuah (2005), noted in their study, that targeted concrete strength may not be achieved due to the silt/clay content in the fine aggregate. The danger of not achieving the recommended strength of concrete by consultant structural engineer during construction, is that the structure built from such concrete with reduced compressive strength will have their structural integrity compromised, and may not be able to carry its intended load, which might ultimately lead to its collapse. Therefore, the aim of this paper is to investigate the effects of concrete grades on strength characteristics of reinforced slender beams.

MATERIALS AND METHODS

The materials used for the production of concrete for this research work were Ordinary Portland cement of grade 32.5, fine aggregates, stone dust, crushed granite of 20 mm maximum size and portable water. The basic material tests were done according to British standards (BS 882, 1992; BS 812, 1985 and BS 1881, 1983). The yield strength of reinforcing bar used, was 370 N/mm^2. The proportions of materials for beam concrete mixes are given in table 1.

Four (4) reinforced concrete slender beams were cast from concrete grades of 5.7 N/mm^2, 9.2 N/mm^2, 12.5 N/mm^2 and 15 N/mm^2 respectively. The beams were loaded with a point load at the beam centre using universal testing machine. The shear span to depth ratio of the beam loaded at the centre with a point load was 3.8. Each of the beams was reinforced at the top and bottom with 2Y12 mm bars, with shear reinforcement of Y8 bars at 100 mm centres. The cross-sectional dimension of the beams was 100 mm x 150 mm with overall length of 1000 mm.

Table 1: Proportion of Material for Beam Concrete Mixes

Material		Quantity			
		5.7G	9.2G	12.5G	15G
Water/Cement ratio		0.6	0.6	0.6	0.6
Water (kg/m^3)		3	4.8	4.8	4.8
Cement (kg/m^3)		5	8	8	8
Fine	% Sand	15	16	12.8	6.4
Agg. (kg/m^3)	% Stone dust	-	-	3.2	9.6
Coarse Agg.(kg/m^3)		30	32	32	32
Total Volume (m^3)		0.015	0.015	0.015	0.015

The load was applied at a steady rate on the beam until failure occurred. The readings for the collapsed load of the beams were taken, with the beam displacements. The flexural and shear strengths of the beams were determined from the readings taken. The flexural tests carried out on the beams were in accordance with BS EN 12390-5 (2009).

RESULTS AND DISCUSSION

The beams were subjected to a point load at the beam centre, until the beam failure occurred. Results of the flexural tests are presented in Table 2. The bending stress of the beams was calculated using Equation 1.

$$\sigma_{ABS} = \frac{3PL}{2bd^2} \qquad 1$$

Where: P = the ultimate load, L = beam span, b = beam width and d = effective depth of beam = 131 mm.

From Table 2, beams B1, B2, B3, and B4 were loaded with a point load at the centre and failed under 40.03 kN, 46.55 kN, 53.01 kN and 59.52 kN loads respectively. The shear forces at failure were 20.02 kN, 23.28 kN, 26.51 kN and 29.76 kN while the displacements at failure were 15.67 mm, 20.58 mm, 24.97 mm, and 28.70 mm for beams B1, B2, B3 and B4 respectively. These results indicated that the displacements depend not only the percentage area of reinforcements provided, but also on the beam concrete grades. From Table 3, for beam B1 with 5.7 concrete grade, the ultimate load at failure was 40.03 kN, while for beams B2, B3 and B4 with concrete grades of 9.2, 12.5 and 15 failed at the ultimate loads of 46.55 kN, 53.27 kN and 59.52 kN respectively. This shows that as concrete grade increases, the ultimate load increases.

Table 2: Results of flexural test on Beams

Beam No	Weight (kg)	Position of Load	Concrete grades (N/mm^2)	Load at Failure (kN)	Bending Strength (N/mm^2)	Shear Force (kN)	Displacement (mm)
B1	43.60	At center	5.7	40.03	26.24	20.02	15.67
B2	42.70	At center	9.2	46.55	30.52	23.28	20.58
B3	44.00	At center	12.5	53.01	34.75	26.76	24.97
B4	44.90	At center	15	59.52	39.02	29.76	28.70

Table 3: The effect of Concrete grade on strength characteristics of the Experimental beams

Beam type	Concrete grade	P_{AUL} (kN)	V_{AUS} (kN)	σ_{ABS} (N/mm^2)
B1	5.7	40.03	20.02	26.24
B2	9.2	46.55	23.28	30.52
B3	12.5	53.27	26.64	34.75
B4	15	59.52	29.76	39.02

From Table 4, for 16.67%, 38.67% and 62.00% drop in concrete grades, there were 10.50%, 21.79% and 32.75% corresponding drop in the ultimate loads and shear capacities of the beams respectively. The ratio of percentage drop of strength characteristic (i.e. P_{AUL}, V_{AUS} and σ_{ABS}) of beams B1, B2 and B3 when compared with that of B4 were 0.53, 0.56 and 0.63 respectively. Therefore, decrease in concrete grade does not have the same percentage decrease in the strength characteristics of beams. Hence strength characteristics of reinforced concrete beams will be reduced by 53% to 63% of the percentage decrease of concrete grade.

Table 4: The Effect of Percentage Drop in Concrete Grade on Strength Characteristics of the Experimental beams

% Drop in Concrete Grade	% Drop in P_{AUL} (kN)	% Drop in V_{AUS} (kN)	% Drop in σ_{ABS} (kNm)	% Drop in $S_{SC}/\%C_G$
62.00	32.75	32.73	32.75	0.53
38.67	21.79	21.77	21.78	0.56
16.67	10.50	10.48	10.50	0.63
0.00	00.00	0.00	0.00	-

Fig 1: Mode of Failure of Beam B1

Fig 2: Mode of Failure of Beam B2

Fig 3: Mode of Failure of Beam B3

Fig 4: Mode of Failure of Beam B4

Figure 1 shows the mode of failures of beam B1. For beam B1 with concrete grade of 5.7 and deflection 15.67 mm at the ultimate load 40.03 kN, failed by shearing at the support. From Figure 2, beam B2 with concrete grade of 9.2, failed by bending at a load of 46.55 kN, and 20.58 mm deflection. Figure 3 gives mode of failure of beam B3. Beam B3 failed by bending at a load of 53.01 kN with 24.97 mm deflection. From Figure 4, beam B4 failed by flexural-shearing mode of failure at failure load of 59.52 kN, with 28.70 mm deflection. This shows that mode of failure of reinforced concrete beams, depends not only on the ratio of the span to height of beam and the percentage area of reinforcement provided, but also on the concrete grade.

Conclusion: With decrease in concrete grade, there is corresponding decrease in the ultimate load and shear capacity of reinforced concrete beams. Decrease in concrete grade does not have the same percentage decrease in the strength characteristics of beams. Strength characteristics of reinforced concrete beams will be reduced by 53% to 63% of the percentage decrease of concrete grade. Also, the mode of failure of reinforced concrete beams, depends not only on the ratio of the span to height of beam and the percentage area of reinforcement provided, but also on the concrete grade.

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