THE STRENGTH RELATIONSHIP BETWEEN THE CUBE AND CYLINDER

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ABTRACT

Concrete laboratory tests compressive strengths differ in a laboratory depending on whether the shape of the concrete specimen is either a cube or a cylinder. General assumption has defined the cylinder to possesses, approximately 80 % of the cube strength. The validity of this approximation needs to be assessed; as several studies have shown this approximation to be invalid.

This investigation assessed the effect of compressive strength and curing age of concrete on the Cylinder–Cube Strength Relationship (CCSR) of South African Concretes.

Cubes and cylinders were cast for 7, 28 and 56 day curing ages from 36 concrete mixes varying in strength, aggregate type and cement type. Concrete strength did not influence the CCSR, but rather, the CCSR was influenced by the curing age (r = 0.998). The general CCSR values were 83.66 %, 84.88 % and 86.96 % (on average) for 7, 28 and 56 day concrete, respectively. The overall average CCSR, calculated considering results across all curing ages, was 85.17 %.

This research shows that 80 % is not an accurate representative value of the average CCSR for typical concretes varying in composition. In addition, this study also acknowledged that the CCSR cannot simply be represented by a single value. This research does however propose that if there should be a value that provides a better guideline to what can generally be expected, should accuracy not be a requirement, an average CCSR of 85 % should be adopted, as opposed to 80 %.

Keywords: Concrete, Strength, Cube, Cylinder

1. Introduction

Knowing the actual compressive strength of concrete is important to both the contractor and the designer in order to ensure that the material meets design requirements. Put simply, determining the compressive strength capabilities of a concrete entails imposing an axial load on a concrete specimen until the material's failure stress is reached.

Though the procedure may not be complicated, interpreting the resulting strength however, requires further assessment. The compressive strength of a specimen during testing does not entirely reflect the strength of the material alone as there are various internal and external factors that affect the resulting compressive strength of a concrete specimen. One of the major factors concerning this study is the concrete specimen shape.

For as long as the compressive strength of concrete has been tested in modern times, the preferred specimen shape has always been in question. This is because the shape of a concrete specimen actually has an effect on the resulting compressive strength. The two main specimen shapes used for compression strength tests are the cube and the cylinder.

The main factor contributing to the difference between the cube and cylinder is the influence of frictional constraint occurring between the platens of the testing machine and the bearing faces of specimens. These frictional constraints increase the apparent strength of a specimen. Hansen et al. (1962) showed how the influence of frictional constraint on the resulting compressive strength can be nullified if the height-to-width ratio of a specimen is 2 or more. For this reason, the cylinder height-to-width ratio is 2 whereas a cube's ratio is 1. Despite the findings of Hansen et al. (1962), the cube specimen is still used in some countries (including South Africa), mainly due to the fact that it is easier to prepare and test in comparison to the cylinder.

Countries differ in preference for either the cube or the cylinder for testing concrete compressive strength. Most countries adopt the cylinder test for their national standard. Due to the division of specimen shape preference, a general strength relationship between the strengths of the two shapes was determined.

The British Standard 1881: Part 4 (1970), which has been withdrawn, originally stated that the strength of the cylinder was four-fifths of the strength of the cube (i.e. CCSR = 80 %), a value that has seemed to have been embedded in civil engineering circles ever since. Research by Elwell and Fu (1995) presented varying values of this relationship in a table from various authors. The table showed the relationship to vary from as much as 0.51 to 0.96 (i.e. CCSR between 51 % and 96 %). More recently, and with perhaps more detail, the Eurocode in particular provides a table listing of cube strength equivalents from the cylinder ranging from 15 MPa to 90 MPa (Beeby and Narayanan, 2005) as opposed to single value.

This study re-assesses the average CCSR, according to South African concretes varying widely in composition, through the testing of a total of 108 specimen sets for both the cube and the cylinder, where each specimen set differed in strength, aggregate type, cement type and curing age. An average CCSR value was determined for concretes at curing ages of 7, 28 and 56 days. Finally, this study produced an overall average CCSR value representing all specimen pairs regardless of curing age.

1. Experiment details

1.1 Materials

A total of four different cement types were used namely a CEM I 52.5N, CEM II 42.5N, CEM III 32.5N and the fourth cement type was a CEM II 42.5N which was further extended on site with 30 % siliceous fly ash. The coarse aggregate utilized were andesite (A), dolomite (D), quartzite (Q) and granite (G). The fine aggregate used were crusher sands of the same aggregate type as the coarse aggregate used for each mix.

1.2 Concrete mix design

There were a total 36 different concrete mixes where each mix varied in composition with differences in strength, aggregate type or cement type. The concrete design was carried out according to the Cement and Concrete Institute (Addis, 2001), a method derived from the ACI Standard 211.1-9 (1997).

1.3 Specimen Preparation

A total of 108 sets of specimens were cast for both the cube and the cylinder where each set contained three identical specimens. Each set represented the strength of a specimen shape for a certain mix at a certain curing age. Therefore each specimen set differed in strength, aggregate type, cement type or curing age. All cylinder specimens were 300 mm in length and 150 mm in diameter and were prepared in adherence to the BS EN 12390-1 (2012). The cube specimen size used was 100 mm and preparations were performed according to the SANS 5860 (2006).

1.4 Specimen testing

All compression strength tests for cylinder specimens were performed according to the BS EN 12390-3 (2009). All compression strength tests for cube specimens were performed according to the SANS 5863 (2006).

1.5 Relationship equation

$$CCSR = \frac{f'c}{f\mathrm{cu}} \times 100 \qquad (1)$$

Where, $f'c$ is the cylinder strength (MPa) and fcu is the cube strength (MPa). The CCSR is represented in percentage (%).

2. Results and Discussion

2.1 Concrete Strength

The CCSR results were calculated and grouped into respective curing ages namely 7, 28 and 56 days to assess the effect of compressive strength on the CCSR. Fig. 1 displays the results with the aim of identifying a relationship between CCSR and concrete compressive strength. The cube strength was specifically used in Fig. 1 because cube specimens are commonly used to determine concrete compressive strengths in South Africa.

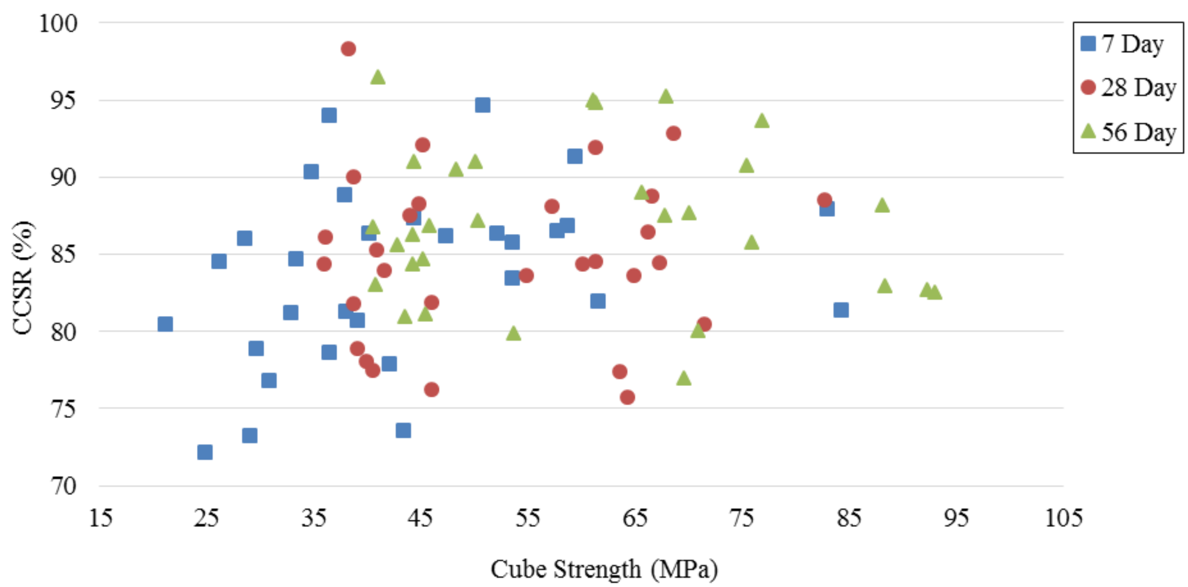

Fig. 1. The effect of compressive strength on the CCSR

Fig. 1 is a plot of CCSR against compressive strength. As can be seen by the large scatter of data points, it is evident that there is no general trend between CCSR and the cube compressive strength at any of the curing age.

2.2 CCSR at different curing ages

In adherence to the SANS 5863 (2006), this research study only included the results of specimens that had met the acceptance criteria stipulated by the code. The SANS 5863 (2006) makes mention that test results for a concrete are deemed valid when the difference between the highest and lowest result of the three specimens do not exceed 15 % of the mean result. The data are displayed in Figs. 2–4 showing the CCSR of each concrete mix for 7, 28 and 56 days, respectively. The results from Figs. 2–4 were used to produce the data for Fig. 5 (showing the percentage difference of the 28 and 56 day strengths relative to the 7 day strength) and Table 1 (the average CCSR value for each curing age).

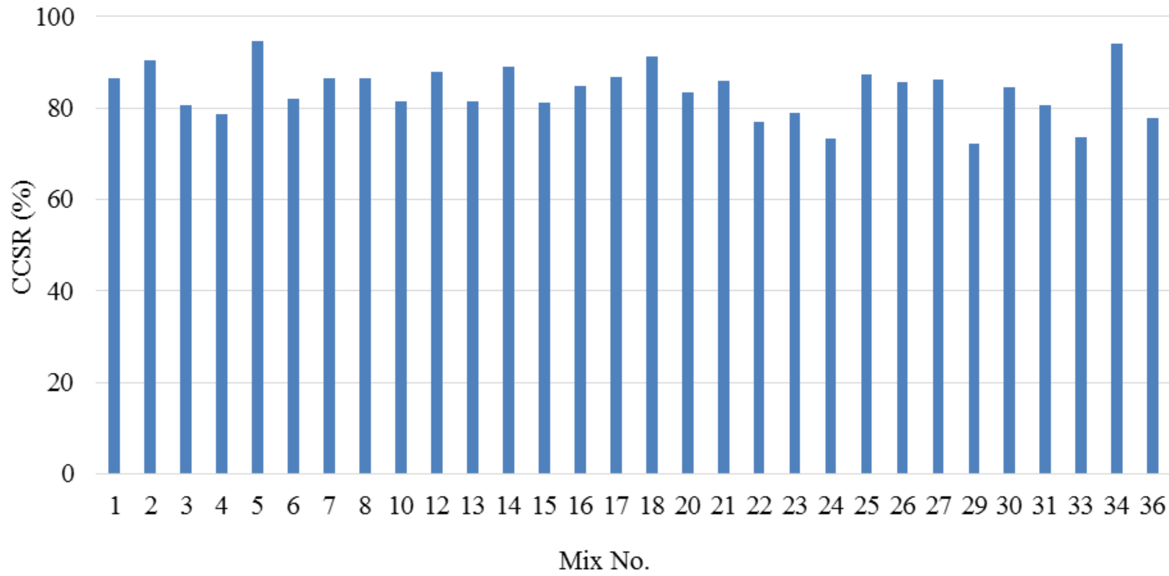

Fig. 2. The CCSR values for concrete cured at 7 days

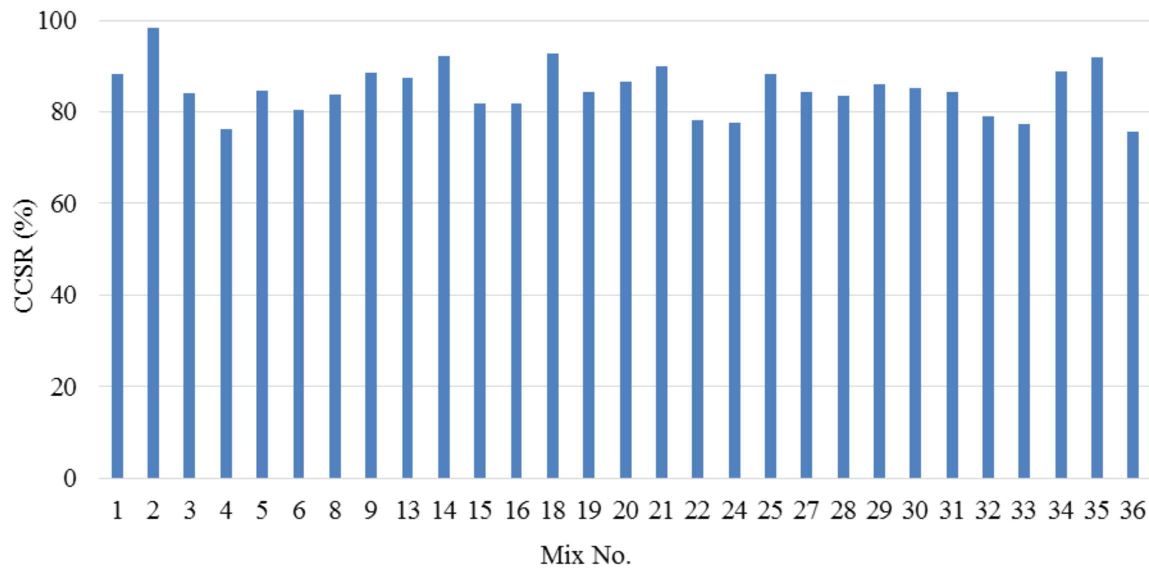

Fig. 3. The CCSR values for concrete cured at 28 days

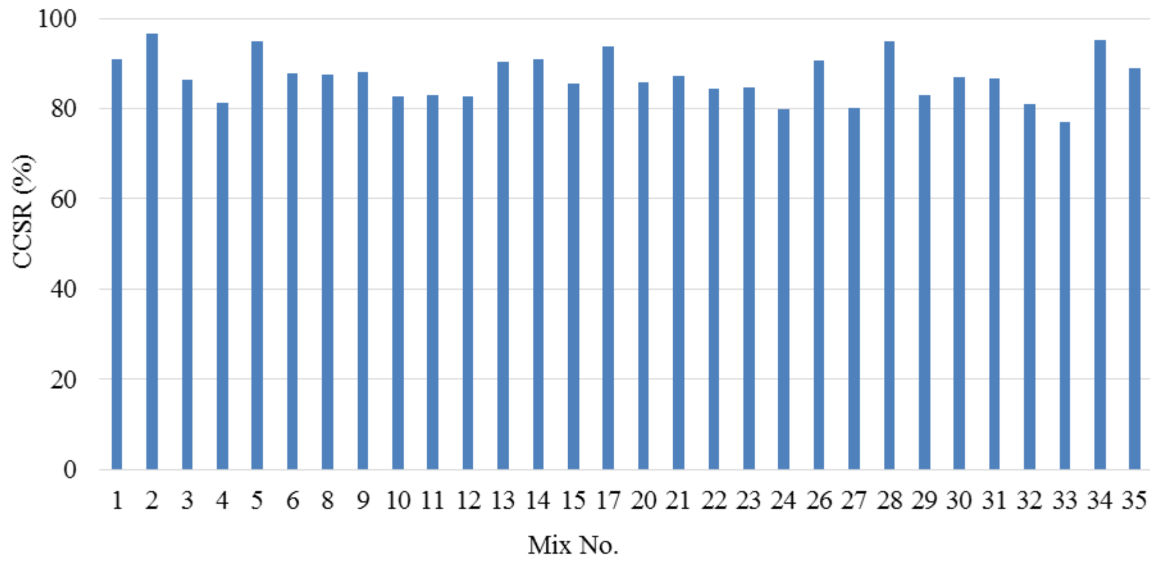

Fig. 4. The CCSR values for concrete cured at 56 days

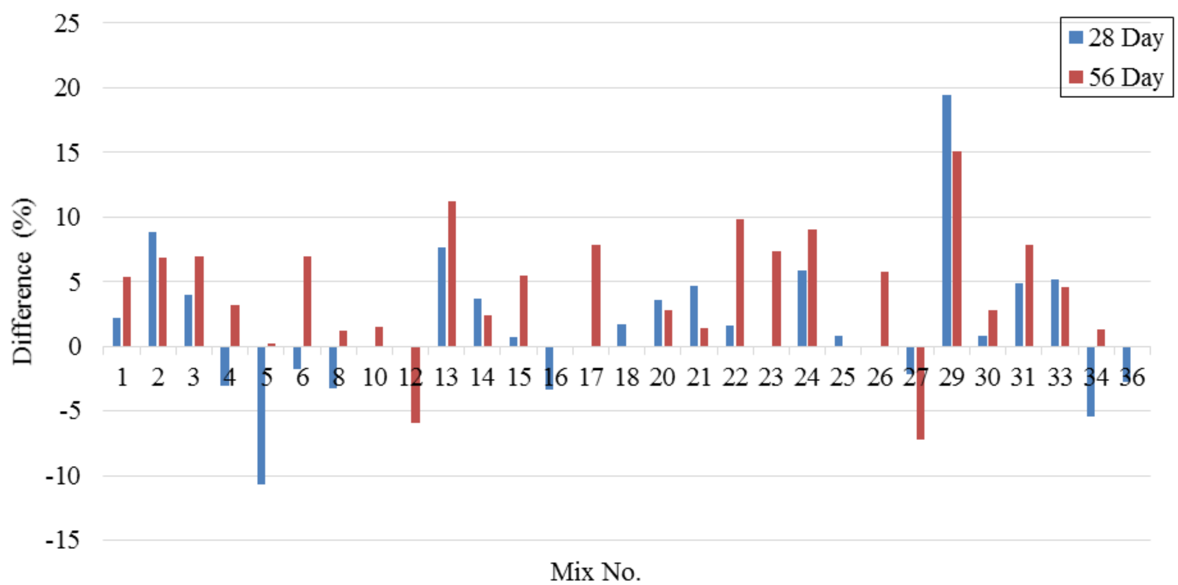

Fig. 5. The percentage difference between the CCSR values of 28 and 56 day cured concrete in relation to the 7 day cured concrete

In Fig. 5, as expected, the majority of the 28 and 56 day CCSR results were greater than that of the 7 days. Furthermore, there are no evident trends showing 28 day CCSR values to being consistently lower or higher than the 56 day CCSR results.

Table 1. The average CCSR at different curing ages

Statistics	Curing Age		
	7 day	**28 day**	**56 day**
Average CCSR (%)	83.66	84.88	86.96
Maximum CCSR (%)	94.63	98.34	96.48
Minimum CCSR (%)	72.16	75.77	77
Average Δ % relative to 7 day CCSR	-	1.46	3.94
Minimum Δ %	-	0.72	0.2
Maximum Δ %	-	19.38	15.11
Variance	32.66	29.60	25.77
Standard Deviation	5.72	5.44	5.08

Table 1 indicates a slight increase in the average CCSR with increasing days of curing. This is evident when the average percentage difference CCSR for 28 and 56 days are calculated in relation to the average 7 day CCSR results. The relationship correlation between the average CCSR (%) values and the curing age was also shown to be statistically significant yielding a correlation coefficient of 0.998. However, in the same table, the minimum and maximum percentage differences for 28 days were both higher than the minimum and maximum percentage differences for the 56 days.

It was also observed that the maximum and minimum values of CCSR ranged quite widely for each curing age with instants of maximum CCSR values being closer to 100 % and minimums being closer to 70 %. This suggests that accurate strength calculations of the cube from the cylinder or *vice versa*, within a curing age, cannot necessarily be encompassed under one single CCSR value for concretes with varying compositions. However, having said this, the usefulness of an average CCSR for each curing age does provide a general guideline but should in no case be utilized where accuracy in strength conversions are required.

2.3 Overall average CCSR

In considering the overall average CCSR, all the compression strength data were included. The resulting overall average CCSR was therefore based on a total of 291 strength comparisons between the cubes and companion cylinders. Each of the 291 comparisons resulted from 97 different concrete types where each concrete type differed in aggregate type, cement type or curing age. The inclusion of these different concretes enabled this research to determine an average CCSR that represented a wider spectrum of concretes.

With each of the concrete couples differing in aggregate type, cement type and curing age, the overall average CCSR was 85.17 %. This result was similar to the findings of Lyse and Johansen (1962) who found the average CCSR as being 86 %.

It should be stated with reference to Table 1 that due to the widely ranging CCSR values within each curing age, 85.17 % strictly represents only a general guideline to the relationship. This study does not suggest that such a value be utilized were accuracy is required as it is not possible to provide a reliable CCSR value to estimate strengths for widely varying concretes.

3. Conclusions

The following conclusions can be drawn from this study:

- Concrete compressive strength was not found to be as influential on the CCSR for concretes varying widely in composition.
- The curing age of concrete had better influences on the resulting CCSR. The CCSR increased with an increase in curing age even though the concretes had all varied widely in composition.
- The average CCSR for 7 day cured concrete was 83.66 %
- The average CCSR for 28 day cured concrete was 84.88 %
- The average CCSR for 56 day cured concrete was 86.96 %
- The overall average CCSR was found to be 85.17 % which provides a better representation of the relationship (as opposed to 80 %).
- The CCSR values vary inconsistently for concretes varying widely in composition. The average CCSR values serve as only general guidelines and should not be utilized for purposes where accuracies in strength conversions are a requirement.

4. Acknowledgements

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