Compressive Strength of Concrete Cylinders by Sulphur, Rubber Capping and Grinding Methods

Ion Dumitru, Tony Song, Vasile Caprar, Valentin Mukhin
Boral Construction Materials (NSW/ACT)

Synopsis: The concrete industry relies heavily on the measured concrete compressive strength to make momentous decisions. The real situation is that no matter how carefully a cylinder is finished, its end surface probably exhibits some irregularities. As required by AS 1012.9, the finished end of a concrete cylinder must be capped or ground before it is crushed for compressive strength. Sulphur and rubber capping are widely accepted methods. However, care must be taken for sulphur capping method especially for high strength concrete, where capping thickness of 1-2 mm and adequate strength of capping compounds are required. Rubber capping method is not permitted in AS 1012.9 for testing concrete strength over 80MPa. Alternatively, concrete cylinders can be ground using a grinding machine. Data presented in this paper compares the effects of four types of cylinder preparation methods on compressive strength, including sulphur capping, rubber capping, single end grinding and double ends grinding. A total of 152 concrete cylinders (i.e. 100x200mm) were used to build as more data as possible for the statistic analysis. These concrete cylinders were crushed as per AS 1012.9 with compressive strengths between 45 and 110MPa.

Keywords: compressive strength, sulphur capping, rubber capping, grinding, quality control

1. Introduction

No matter how carefully a cylinder end is finished, its end surface probably will exhibit some irregularities. As required in AS 1012.9, the finished end of a concrete cylinder must be capped or ground before it is crushed for compressive strength. When concrete strength is less than 80MPa, both sulphur capping and rubber capping methods are permitted. For concrete strength over 80MPa, sulphur capping is allowed. Rubber capping is not permitted in AS 1012.9. However, care must be taken for sulphur capping method for high strength concrete, where capping thickness of 1-2mm and adequate strength of capping compounds are required. Alternatively concrete cylinders can be ground using a grinding machine.

The influence of capping methods on compressive strength has been studied overseas. For lower strength concretes (i.e. below 35MPa), Richardson (1) compared the sulphur capping and rubber capping methods using 300mm × 150mm cylinders. He found out that the overall mean strength of the two capping methods were not significant different. Carino etc (2) reported that, for the 45MPa concrete, there was no strength difference due to the end preparation (i.e. sulphur capping and grinding), but for the 90MPa concrete, grinding resulted in as much as 6% greater compressive strength in certain cases.

Not enough literature, if any, is available in Australia to assess the cylinder preparation methods as per Australian Standards. Data presented in this paper compares the effects of four preparation methods on compressive strength as per AS 1012.9. Concrete cylinders were prepared by each of four methods, e.g. sulphur capping, rubber capping, single end grinding and double ends grinding.

2. Experiment Program

2.1 Concrete strength range

A total of 152 concrete cylinders (i.e. 100×200mm) were used. They were cast and standard wet-cured as per AS1012.8. For comparison, concrete cylinders from the same batch were used and crushed at the same ages as per AS 1012.9. The compressive strength of concrete presented in this paper ranged between 45MPa and 110MPa.

2.2 Concrete cylinder preparation methods

- Sulphur capping
- Rubber capping
- Single end grinding
- Double ends grinding

Sulphur capping compounds were prepared separately for two strength grades – less than 80MPa and over 80MPa. The compounds comply with the requirements in AS 1012.9. Even more, for testing concrete strength over 80MPa, the thickness of sulphur cap was strictly controlled within 1-2mm.

Two types of rubber pad were used. The pad with a nominal hardness of 50 to 65 was used for concrete strength of 60MPa grade. The rubber pads with hardness of 75 were used for concrete strength of 80MPa grade.

Concrete cylinders were ground on the Hi-Kenma (Figure 1) grinding machine, which was manufactured in Japan.

Figure 1. Hi-Kenma grinding machine

3. Case Study

3.1 Case study background

A field laboratory was required to test S80 grade concrete. The 7 days density ranged from 2260 to 2340kg/m^3, indicating no major difference in density between cylinders to be crushed for compressive strength. However, the 7 days compressive strength varied from 48.5MPa to 86.5MPa, with the mean compressive strength of 69.1MPa and the standard deviation of 10.6MPa. The 28d strength varied from 51.5MPa to 85.0MPa. These results would initially suggest that the concrete supplied for this project was not satisfactory.

Following an investigation, it was noted that the reasons behind the large standard deviation was due to the inappropriate sulphur capping compounds used.

3.2 Inappropriate sulphur capping used

Eight sulphur capped concrete cylinders from the same batch were delivered to the Baulkham Hills laboratory at Boral Materials Technical Services, Sydney. Two cylinders were crushed directly while, for the rest 6 cylinders, the sulphur caps were removed and concrete cylinders were then ground before crushing. Table 1 presents the results.

Table 1. Incorrect strengths due to the inappropriate sulphur capping materials used

End preparation method	Individual compressive strength value (MPa)
Capped by inappropriate sulphur capping compound	58.5, 75.1
Grinding	93.0, 93.5, 94.4, 98.2, 105.2, 99.4

It is noted from Table 1 that concrete cylinders with sulphur capping still gave much lower results and, by contrast, those ground cylinders gave much higher results, indicating the concrete was indeed a S80 grade.

Further investigation revealed that the sulphur capping material used was a commercial product, which was designed to test the normal concrete rather than the high strength concrete. Therefore, the application of an inappropriate sulphur capping material for high strength concrete gave the incorrect strength values even though there was nothing wrong with the concrete cylinders and the sulphur cap composition.

4. Research Program

A research program was carried out to intensively investigate the influence of sulphur capping, rubber capping and grinding methods on compressive strength. The results are presented and discussed as follows:

- The dispersion of the individual strength,
- The mean strength value,
- the coefficient of variation (COV)
- Strength difference (the highest strength minus the lowest one).

4.1 Effects on the dispersion of individual strength value

The individual strength values are presented in Figure 2.

It becomes apparent that, for concrete strength of 45MPa and 60MPa, all individual strength values appeared constantly regardless of the end preparation methods. However, for concrete strength of 80MPa and 110MPa, the dispersion became more obviously, especially in the case of rubber capping method.

It is noted that concrete cylinders with double end grinding method gave the compressive strength quite constant for all strength grades.

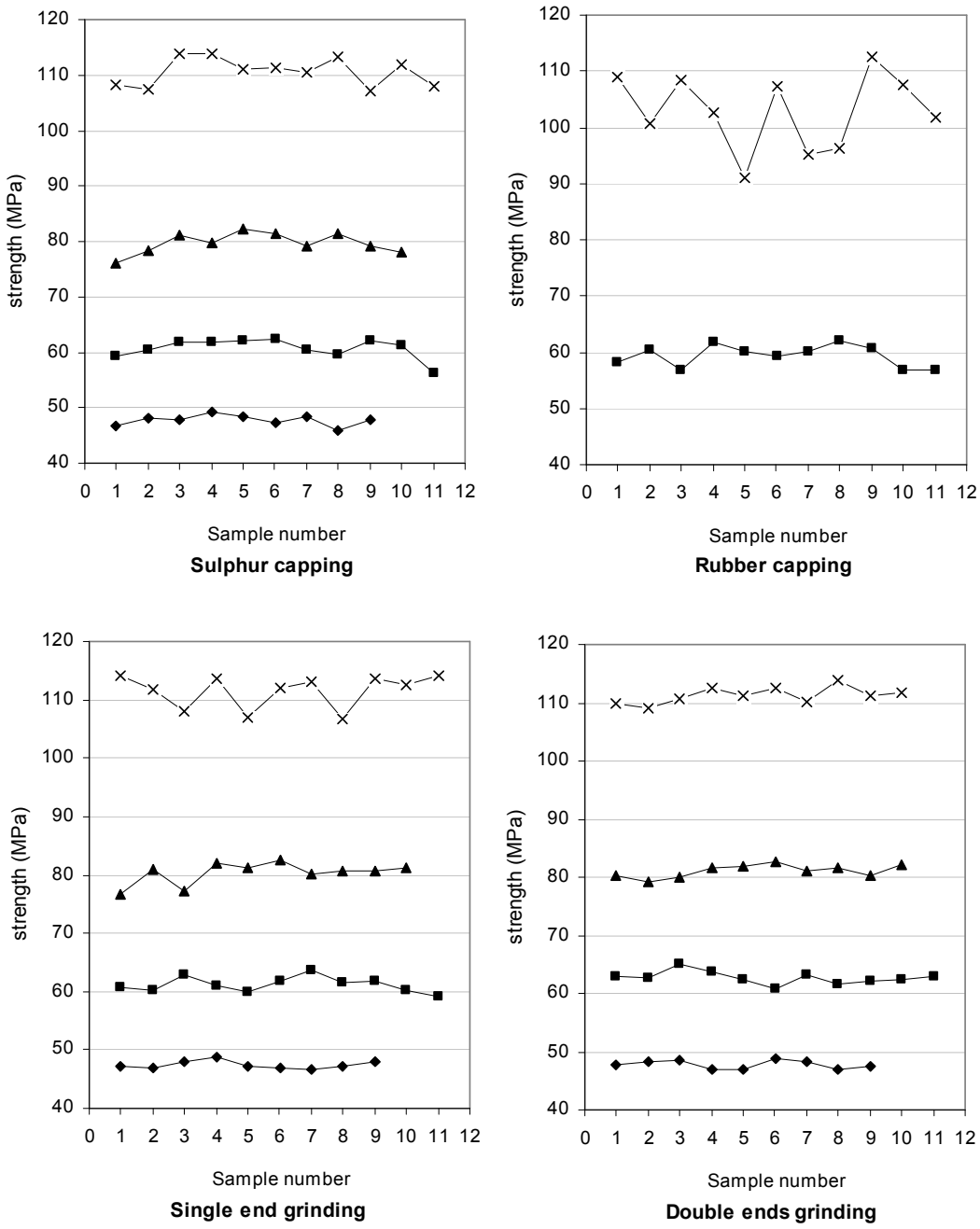

Figure 2. Dispersion of individual strength value

4.2 Effects on the mean compressive strength

For each strength level, the mean value of sulphur capped concrete cylinders was regarded as 100%. The mean values from other methods were then assessed and presented in Figure 3.

In comparison with sulphur capping, when concrete strength is 45MPa, there is almost no difference between sulphur capping and grinding methods. However, the ground cylinders resulted in about 1-3% higher compressive strengths for the high strength concrete.

In comparison with sulphur capping, rubber capped cylinders gave about 2% and 7% lower mean compressive strength for 60MPa and 110MPa concrete, respectively. Subsequently, rubber method is not recommended when concrete grades are between 60-110MPa.

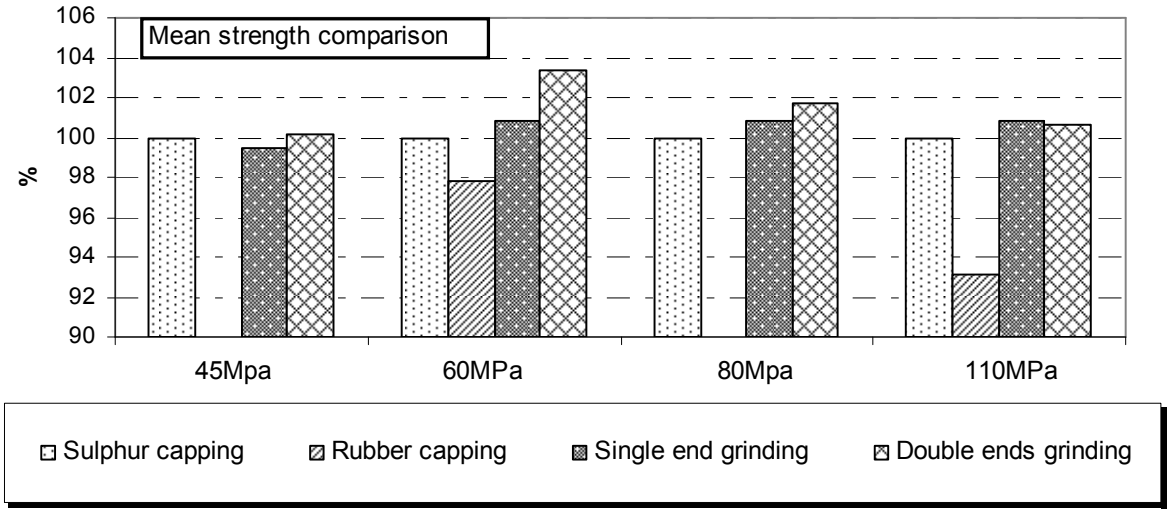

Figure 3. Effects on the mean strength compared by percentage

4.3 Effects on the coefficient of variation (COV)

The coefficient of variation (COV) as presented in Table 2 is the ratio of the standard deviation and its mean compressive strength. COV is normally used to assess the overall dispersion of test results. It is noted that

- The double end grinding method has the lowest COV value of 1.3-1.6%,
- The single end grinding method has a satisfactory COV value of 1.3-2.1%,
- The sulphur capping method has a reasonable COV of 2.1-3.1%.
- For concrete of 60MPa, rubber capping has its COV of 3.3%. However, the COV was as high as 6.5% for concrete of 110MPa.

All COV values for sulphur capping and grinding methods are lower than the COV of 3.2%, given in ASTM C39 (3) for a 100x200mm standard cylinder. This means that these concrete cylinders used in this investigation have constant and high quality in terms of compaction, curing, capping & grinding and crushing.

The very high COV of 6.5% for the case of rubber capping method strongly supports why AS 1012.9 does not allow the utilisation of rubber capping when concrete is over 80MPa.

Table 2. Effects on the COV

End preparation methods	45MPa Value (%)	60MPa Value (%)	80MPa Value (%)	110MPa Value (%)
Sulphur capping	2.1	3.1	2.4	2.3
Rubber capping	N/A	3.3	N/A	6.5
Single end grinding	1.3	2.1	2.4	2.6
Double ends grinding	1.6	1.8	1.4	1.3

4.4 Effects on the strength difference

The strength difference is the highest strength minus the lowest value. The results are presented in Table 3.

Basically the compressive strength difference increases when the strength grade changes from 45MPa-110MPa. For 45MPa concrete, sulphur capped cylinders had the difference value of 3.3MPa while grinding method had a lower value of approximately 2.0MPa.

For concrete strength of 110MPa, the difference was significant affected by the end conditions. The worst case is the rubber capping method, with difference as high as 21.6MPa. The best case is the double ends grinding, having the smallest difference of 4.9MPa. The sulphur capping and single end grinding had similar level with the difference of 7MPa.

It must be stressed that the sulphur capping compounds were specially designed and capping thickness was carefully controlled. It is therefore noted that sulphur capped concrete cylinders gave as good results as single end grinding method.

Table 3. Effects on the strength difference

End preparation methods	45MPa Value (Mpa)	60MPa Value (Mpa)	80MPa Value (Mpa)	110MPa Value (Mpa)
Sulphur capping	3.3	6.3	6.2	6.9
Rubber capping	N/A	5.3	N/A	21.6
Single end grinding	1.9	4.4	5.9	7.5
Double ends grinding	2.0	4.3	3.4	4.9

5. Conclusions and recommendations

- Concrete cylinders with double end grinding method gave the compressive strength values quite constant for all strength grades. When concrete grade is 80MPa or less, single end grinding and sulphur capping methods achieved relatively constant results. The dispersion became more obviously in the case of rubber capping method.
- For concrete strength grade of 45MPa, there appeared to be no significant differences between the mean compressive strength of the sulphur capped and the ground cylinders. However, in comparison with sulphur capping method, the ground cylinders resulted in about 1-3% higher mean compressive strengths in high strength concrete. For concrete strength grade of 60-110MPa, rubber capped cylinders gave about 2-7% lower mean compressive strength when compared with sulphur capped cylinders.

- The dispersion, in terms of coefficient of variation (COV), was significantly affected by the end preparation methods. The double end grinding method has the lowest COV value of 1.3-1.6%, single end grinding having a satisfactory COV value of 1.3-2.1%, and sulphur capping having a reasonable COV of 2.1-3.1%. For concrete strength of 60MPa, rubber capping had its COV of 3.3%. However, the COV was as high as 6.5% for concrete of 110MPa and when rubber capping was used.
- Overall, grinding method can be used for all strength grades for reliable strength results. Sulphur capping and rubber capping methods achieved reasonable results when strength level is lower (i.e. 60MPa). For the high strength concretes, rubber capping method cannot be recommended. Sulphur capping method can be used but the sulphur camping compound must be tested and comply with AS 1012.9 and the capping thickness must be 1-2mm. Otherwise, incorrect compressive strength could be obtained as demonstrated in the case study.

6. References

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