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# AGGREGATE SIZE AND LATERAL DIMENSION EFFECTS ON CORE COMPRESSIVE STRENGTH OF CONCRETE

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## ABSTRACT

The compressive test on drilled concrete cores is the most reliable method to determine the concrete strength of existing structure. This paper reports on a recent laboratory investigation devoted to the effect of maximum aggregate size and core diameter on the estimation of the characteristic strength of current concrete (C25/30 class). The compressive strength of concrete cores with different diameters (ϕ = 100 mm, 75 mm and 50 mm) and with a slenderness ratio of 2 is determined. These lateral and longitudinal core dimensions (respectively ϕ and h) are the most used in building sites in order to check hardened concrete strength. Concrete mixtures are prepared with different maximum aggregate sizes ($D_{max}$= 4 mm, 8 mm, 16 mm and 25 mm). The cores tested are extracted from massive blocks of these concrete formulations.

The results show the increase of the compressive strength of cores as the diameter is increased. The strength values of the concrete cores with diameter ϕ = 100 mm and 75 mm are greater than 80 % of the characteristic strength of the tested concrete. However, the resistance values of the cores drilled with the smallest diameter ϕ = 50 mm are largely dispersed. The evolution of the core strength values as a function of maximum aggregate size shows an irregular enhancement as the aggregate size is increased. In addition, the result dispersions represented by the coefficient of variation diminishes substantially as the core diameter is increased. Correlation formulae between core diameters and concrete characteristic strengths are also pointed out.

***Keywords:*** Concrete core, compressive strength, size effect.

## INTRODUCTION

In civil engineering, the concrete quality control is mainly based on the assessment of the concrete compressive strength. The most common technique to estimate the compressive strength of concrete in existing structures is the destructive test of the drilled core (Bartlett, 1994). The dimension of the core should be small as possible in order to limit the weakening of the structure (Tuncan, 2008). Generally, the American and European standard recommends the use of 100 mm x 200 mm core dimensions. Nevertheless, drilling cores when the slenderness ratio of the specimens is fixed to 2 is conditioned by the thickness of the building elements and the reinforcing steel density. However, attempts to use a drilled core with diameter less than 100 mm faces the complex correlation problem of their resistance to the characteristic strength of the concrete, which is still under investigation (Jiahai, 2015). Indeed, the core strength depends on numerous parameters such as slenderness ratio (h/ ϕ), diameter, coring direction and moisture condition at the testing time (ACI, 2014). Moreover, some disturbing factors resulting from the operation of extraction should be considered (Uva, 2013). For instance, the h/ϕ ratio of the specimen is more effective for small diameter cores, whereas the core size has negligible effect on their strength (Nikbin, 2009). However, from their investigation, the coefficient of variation of strength values for 50 mm diameters cores is noticed to be somewhat higher. This conclusion is corroborated by (Khoury, 2014), in their study, where a strength reduction up to 17 % is recorded for cores with diameter less than 100 mm. Similarly, a compressive strength reduction of about 7 % for cores with 100 mm diameter and 200 mm height when compared to that of the standard ones (150 mm x 300 mm) is reported by (Carrasquillo,1988), who highlighted also that the influence of aggregate size regarding the core diameter is more critical for small cores. Furthermore, the small cores are found to be more susceptible to damage during drilling as pointed out by (Bartlett, 1994). Indeed, the homogeneity of the materials is reduced and affects drastically the internal failure characteristics (Bungey, 1979).

In this contribution, an experimental study of the effects of core diameter and aggregate size on compressive strength of drilled concrete cores is presented. This study only deals with axial compression of cores with diameters ranging from 50 mm to 100 mm and a slenderness ratio of 2 with four current (C25/30) concrete formulations, using different maximal aggregate sizes.

## MATERIALS AND TESTING PROGRAM

### Concrete mixture

In this study, an ordinary Portland cement (CEM II/A 42.5) was used in the concrete formulations. The cement specific surface and gravity are respectively 4000 $cm^2/g$ and 3.15.

Local sand of 0/4 mm was used as fine aggregate. The fineness modulus and the proportion of fines are respectively 3.8 and 5.2 %. These properties were determined throughout the test procedure described in NA 2607 standard.

Three different types of crushed gravel were selected as coarse aggregates. The maximum aggregate sizes $D_{max}$ are 8, 16 and 25 mm with respective flattening coefficients of 19.1, 18.5 and 16.7 %. The resistance to fragmentation determined according to NA 5130 standard (2009) and represented by the Los Angeles coefficient is around 24. The proportions of fines and coarse aggregates are listed in Table 1.

Table 1 - Fines proportions of the coarse aggregates

| Size of gravels (mm) | Fines (%) ≤ 0.063 mm |
|---|---|
| 4/8 | 0.9 |
| 8/16 | 0.7 |
| 16/25 | 0.2 |

### Concrete preparation

The concrete mixture proportions of the massive blocks are summarized in Table 2. The standard C25/30 concrete class with a slump in the range of 50 mm to 90 mm (consistency class S2) was prepared. The concrete was casted in mould and left for cure age of 28 days.

Table 2 - C25/30 concrete mixture proportions

| Dmax (mm) | Water/Cement | Sand/Aggregate (%) | Water ($l/m^3$) | Cement ($kg/m^3$) | Sand ($kg/m^3$) | Gravel ($kg/m^3$) |
|---|---|---|---|---|---|---|
| **4** | 0.605 | - | 244 | 403 | 1672 | - |
| **8** | 0.59 | 56 | 226 | 382 | 977 | 754 |
| **16** | 0.57 | 47 | 204 | 357 | 862 | 978 |
| **25** | 0.614 | 44 | 194 | 316 | 776 | 1003 |

## Cores drilling and testing program

The cores were extracted from massive blocks by using a diamond tipped drilling machine. The drilling direction is perpendicular to the casting axis as shown in Figure 1. The dimensions of the different concrete massive blocks and the number of extracted cores for each one are detailed in Table 3. The extracted cores are left 48 hours at the ambient temperature (T=22 ÷ 25°C) before testing.

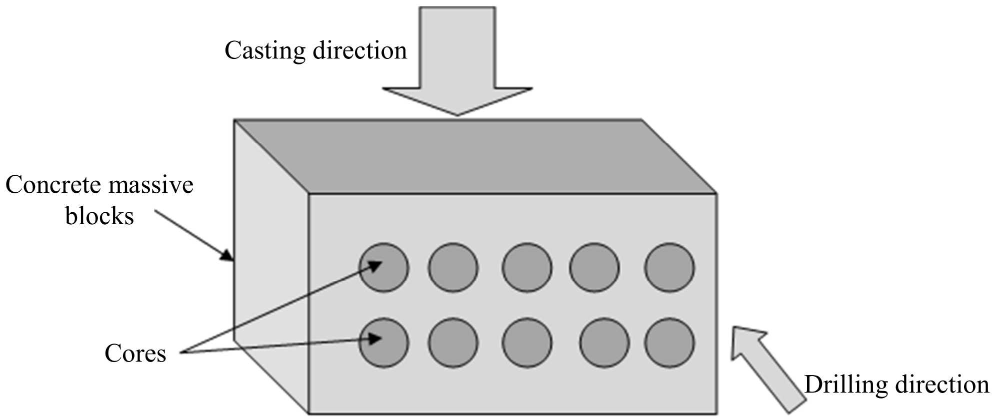


Fig. 1 - Massive concrete block and coring direction

The compression test concerns the drilled cores with three different diameters: $\phi$ = 50 mm, 75 mm and 100 mm and the slenderness ratio is set to2. The number of samples is limited to 9 for each diameter and for the different concrete formulations.

Table 3 - Dimensions of the blocks

| Block dimensions (mm) | Number of the blocks | Core diameter ∅(mm) | Number of cores/block |
|---|---|---|---|
| 880 x 600 x 350 | 12 | 100 | 27 |
| 800 × 550 × 275 | 12 | 75 | 27 |
| 850 × 350 × 200 | 12 | 50 | 27 |

The uniaxial compressive load is applied by using a 3000 kN capacity machine (Figure 2) with a loading rate of 0.2 MPa/s. The cores are sulphur-capped in order to eliminate the fretting between the samples and the loading plates.

Fig. 2 - Uniaxial loading machine

### Data processing

The measurements and experimental data are treated statistically. Because of the variability in the concrete material preparation, the errors in the measurement or during the test should be highly reduced. Hence, the data processing method consists on the detection and the elimination of the aberrant values (outliers). The combined Grubbs-Dixon and Teitjen-Moore criteria are applied in accordance to ASTM E178-16. For this experimental investigation, the significance level is fixed to 5 %.

## RESULTS

### Effect of core diameter

In this section, the strength values of the uniaxial loading in compression of the cores versus their diameter are presented and discussed. The results show globally a linear increase of the compressive strength of the concrete cores as the diameter is increased (Figure 3). As can be seen in the figure, for the various coarse aggregate sizes, the core strength approaches gradually the current concrete characteristic strength as the diameter is increased.

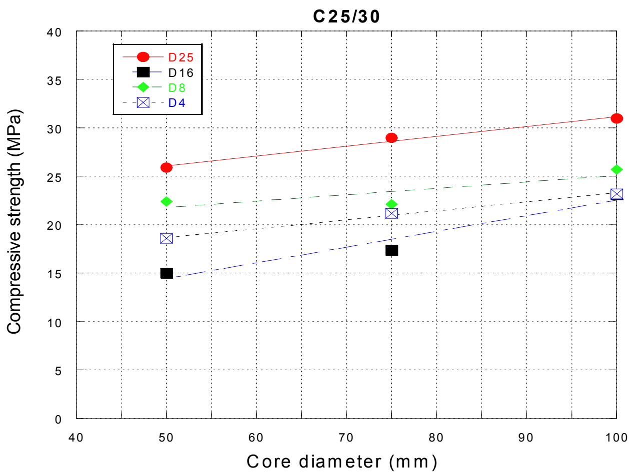


Fig. 3 - Compressive strength as function of  drilled core diameters

Core strengths reported to the characteristic ones of the different tested concrete mixtures are given in Table 4. These ratios are varying between 0.6 and 0.99 for the different tested cores. The highest ratio is observed for the 100 mm core diameter. The smallest and the most dispersed ratios are recorded for 50 mm diameter. In addition, this ratio does not exceed 1 (between 0.74 and 0.99) for 100 mm core diameter, in contradiction with the conclusion found out by (Yip, 1988) in their experiment, where this ratio varies from 0.63 to 1.53.

Table 4 - Regression analysis results

| Maximum aggregate size $D_{max}$(mm) | $\frac{CS_{ø\,100}}{CS_{ø\,150}}$ | $\frac{CS_{ø\,75}}{CS_{ø\,150}}$ | $\frac{CS_{ø\,50}}{CS_{ø\,150}}$ | Correlation laws | CoD ($R^2$) |
|---|---|---|---|---|---|
| **4** | 0.74 | 0.68 | 0.60 | $\sigma_f(ø) = 0.09\, ø + 14.07$ | 0.99 |
| **8** | 0.84 | 0.72 | 0.73 | $\sigma_f(ø) = 0.06\, ø + 18.46$ | 0.68 |
| **16** | 0.85 | 0.64 | 0.55 | $\sigma_f(ø) = 0.16\, ø + 6.33$ | 0.94 |
| **25** | 0.99 | 0.93 | 0.83 | $\sigma_f(ø) = 0.1\, ø + 20.99$ | 0.98 |

Thus, when compared to the characteristic strength of a standard dimension sample (ϕ 150), the mean core strength of the set with a diameter of 100 mm is reduced with a maximum percentage of 25 %. This reduction becomes more important as the core diameter is diminished and can reach up to 40 % for the smallest ones. A low strength reduction for 75 mm and 50 mm core diameters and significantly higher for a 38 mm core diameter were also stated by Khoury, 2014.

Relationships between the experimentally obtained compressive strength of cores and their diameters are obtained by regression analysis, Table 4. Globally, the core strengths are linearly correlated to their diameters, with high coefficient of determination CoD ($R^2$) values varying within 0.99 and 0.68.

## Effect of maximum aggregate sizes

The evolution of the core strength values as a function of maximum aggregate size is depicted in Figure 4. As shown by the figure, the core strength is lightly affected by the maximum aggregate sizes. The core compressive strength is globally increased as the maximum aggregate size increases. The highest compressive strength of cores is recorded for $D_{max}$ = 25 mm. The increase is less marked for $D_{max}$ = 16 mm. This evolution trend of core compressive strength could be related to the aggregate skeleton resistance, becoming more compact by adding progressively coarse aggregates. This strength enhancement conferred by rigid aggregate could be in competition with weakening induced by drilling operations. The effect is more apparent for 50 mm diameter cores. For instance, the difference between the strength of cores extracted from the massive blocks prepared with 25 mm and 16 mm maximum aggregate size is around 42 % with a downward trend, whereas this reduction is limited to 25 % for a 100 mm core diameter.

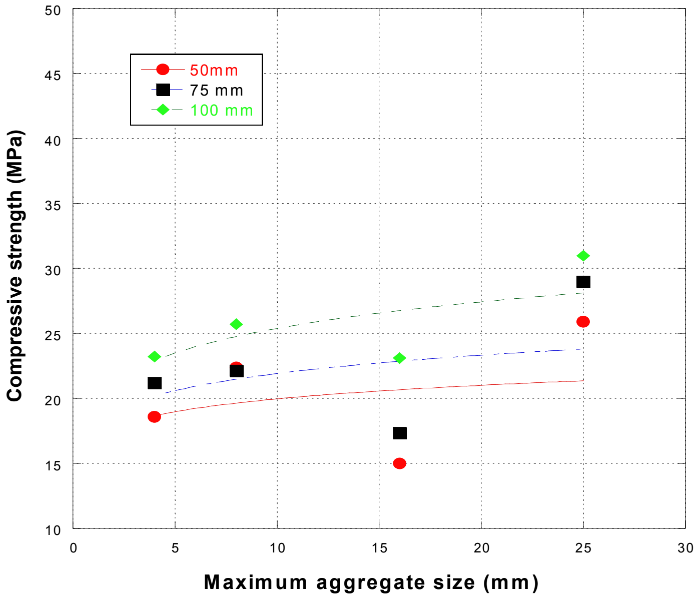


Fig. 4 - Influence of the maximum aggregate size on core compressive strength

The evolution of the coefficient of variation (CoV) of core compressive strengths as function of maximal aggregate size is shown by the histogram below (Figure 5). The CoV of the compressive strength decreases clearly when coarse aggregate are added. The core strength values become stable by increasing the aggregate sizes and enhancing by the way the material density.

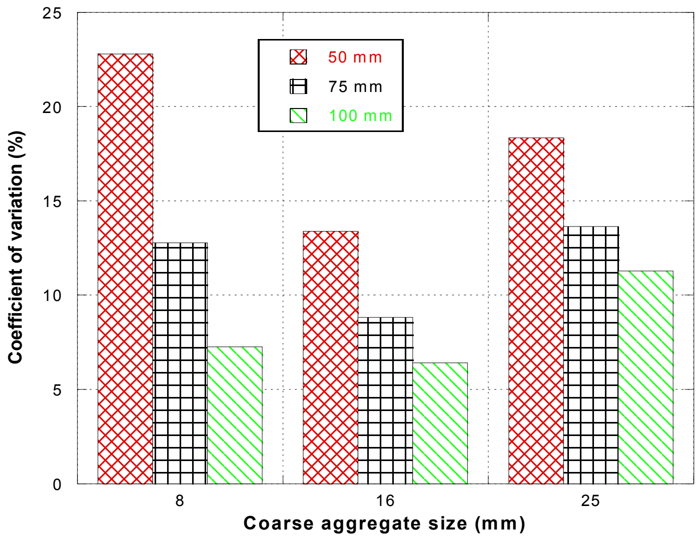


Fig. 5 - Coefficient of variation of the core compressive strengthas function of maximum aggregate size

## CONCLUSION

The influence of aggregate size and core diameter on the estimation of compressive strength of current concrete (C25/30 class) is experimentally studied. From this investigation, the following conclusions can be drawn:

- The compressive strength of cores generally increases with an increase of their diameters.
- The core strength maximal reduction in comparison to those of moulded standard dimension samples is about 25 % for 100 mm and 75 mm diameter and reach up to 40 % for 50 mm diameter.
- The dispersion of the core compressive strength values affects mostly the small diameter (50 mm). This dispersion decreases as the diameter becomes larger.
- The core strength is slightly enhanced by using coarse aggregate. This strength increase seems to be conferred by the denser aggregate skeleton.
- Core strength is found linearly correlated to the studied diameters.

## REFERENCES

[1] ACI Committee 2014.4R-10. Guide for obtaining cores and interpreting compressive strength results. American Concrete Institute 38800 Country Club Drive Farmington Hills, MI 48331 U.S.A. 2010.

[2] ASTM E178-16, Standard practice for dealing with outlying observations, ASTM International, West Conshohocken, PA, 2016.

[3] Bartlett FM and MacGregor JG.Effect of core diameter on concrete core strengths.ACI Materials Journal. 1994, 91(4), pp. 339-348.

[4] Bungey JH.Determining concrete strength by using small diameter cores. Magazine of Concrete Research, 1979, Vol. 31, Issue 107, pp. 91-98.

[5] Carrasquillo P. M. and Carrasquillo R. L. Evaluation of the use of current concrete practice in the production of high strength concrete.Materials Journal. Vol. 85, Issue 1, pp. 49-54. 1988.

[6] Jiahai L., Dingyong Y., Guofu W. and Xiaopeng Q. Size effect of core samples on bridge concrete strength with drilled core method. International Conference on Intelligent Transportation, Big Data & Smart City. 2015.

[7] Khoury S., Aliabdo A. A-H. andGhazy A. Reliability of core test - Critical assessment and proposed new approach. Alexandria Engineering Journal. 2014, Vol. 53, pp. 169-184.

[8] NA (Norme Algérienne) 2607-1. Essai pour déterminer les caractéristiques des granulats; Partie 1: Détermination de la granularité, analyse granulométrique par tamis. 2014.

[9] NA (Norme Algérienne) 5130. Essais pour déterminer les caractéristiques mécaniques et physiques des granulats (Partie 2: Méthodes pour la détermination de la résistance à la fragmentation. 2009

[10] Nikbin I.M., EslamiM. andRezvani D.S.M. An experimental comparative survey on the interpretation of concrete core strength results, 2009, Eur. J. Sci. Res. 37 (3), pp. 445-456.

[11] Tuncan M., AriozO.,Ramyar K. and KarasuB. Assessing concrete strength by means of small diameter cores.Journal of Construction and Building Materials.2008, Vol. 22, pp. 981-988.

[12] Uva G, F. Porco, A.Fiore M. Mezzina. Proposal of a methodology for assessing the reliability of in situ concrete tests and improving the estimate of the compressive strength.Journal of Construction and Building Materials. 2013, Vol. 38, pp. 72-83.

[13] Yip W.K. and Tam C.T. Concrete strength evaluation through the use of small diameter cores. Magazine of Concrete Research.1988, Vol. 40, Issue 143, pp. 99-105.