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Mechanical characterization of concrete: the case of a school building located in Tuscany

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Abstract

Mechanical characterization of concrete is an important step in the knowledge process aimed at assessing RC existing buildings. In particular, concerning structural response of an existing building subject to severe actions, such as the seismic ones, it is important to accurately define the concrete constitutive law, including both the compressive and the tensile branch. Definition of these mechanical properties is usually achieved through laboratory tests, mostly involving cores drilled from the building under investigation. While the compression tests are easy to perform, execution of the tensile tests is more difficult to implement. In this case, indirect tests are usually performed, such as the bending test or the splitting test. The paper presented herein concerns results of both compression and tensile tests (splitting tests) carried out on cores belonging to structures (beams and columns) of a school building located in Tuscany. Each core was interested by both types of tests: the central part of the specimen was used for the direct compression test, while the remaining end portions, resulting from the core preparation, were used for the execution of the splitting test; in this way, specimens involved in tensile tests were about twice those employed for the compression tests. Finally, results provided by laboratory tests were subjected to a subsequent re-elaboration mainly concerning the tensile strength, in order to make a comparison with strength values provided by formulations present in the technical and scientific literature.

Keywords: concrete; existing buildings; compression test; splitting test; case study

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1. Introduction

Mechanical properties of concrete are usually evaluated through two main types of test: i) direct compression test, and ii) indirect tensile test. The first type of test is the most commonly performed and consists in the application of an axial compression on cubic or cylindrical specimens of standard dimensions until rupture. The tensile test is more difficult to achieve, so it is usually performed by indirect methods. These tests are usually executed in official laboratories according to procedures established by the UNI standards (UNI EN 12390-3: 2009 for new concretes and UNI EN 12504-1: 2009 for samples obtained from existing structures).

Being the tensile strength of concrete of more uncertain evaluation, such mechanical property is usually estimated through three alternative procedures: direct tensile test, bending test and splitting (or Brazilian) test (Figure 1). The first testing procedure consists in the direct application, up to rupture, of an increasing tensile force to the concrete specimen according to the UNI 6135 (1972) standards. Due to difficulties in performing this type of test, this procedure is rarely applied; in fact it is preferable to adopt indirect methods such as the bending test and the splitting test. The bending test allows estimating the strength of the concrete by a four points load scheme on a prismatic specimen until rupture [UNI EN 12390-5, 2009]. Splitting test provides longitudinal compression along two diametrically opposed generators, parallel to the axis of the concrete specimen, cylindrical or cubic, according to the UNI EN 12390-6 (2010) standards; in this case, a stress representative of the tensile strength of the concrete is generated at rupture in the diametric plane containing the load line.

This work illustrates the results of an experimental campaign aimed at evaluating both compressive and tensile strength of concrete belonging to an existing school building located in Tuscany (Italy). Results given by laboratory tests, particularly the ones obtained from the tensile splitting tests, were compared with strength values provided by formulations present in the technical and scientific literature.

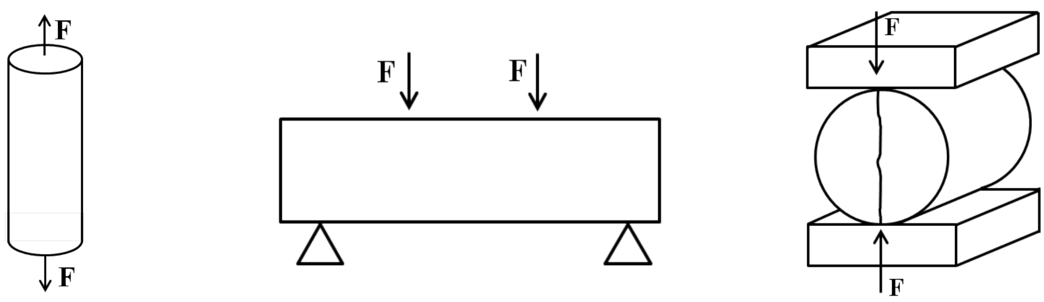

Fig. 1. Methods for the evaluation of tensile strength: a) direct test; b) bending test; c) splitting test.

2. Laboratory tests and elaboration of results

Laboratory tests (compression and splitting tests) were executed at the “Official Laboratory for Tests on Material and Structures” of the Department of Architecture – DiDA of the University of Florence. Tests involved a significant number of specimens, with diameters ranging from 44 to 104 mm, obtained by cores extracted from an existing RC school building located in San Godenzo, a country near Florence, before its demolition. The school was built in the mid-70s and was subjected to an early investigation by the technical department of the Regione Toscana that decided the demolition owing to problems in the seismic design, as reported in Cristofaro et al. (2016). Eight structural elements (two beams and six columns) were taken from the building, stored in a way to simulate previous conditions.

A total of 232 cores were extracted; however, results reported in this work concern only cores that allowed obtaining specimens for both compression and tensile tests (181 cores). The data and position concerning cores extracted from different structural elements are shown in Table 1 and Figure 2.

Table 1. Structural elements and core diameters.

Struct. element	Type of element	Section size *bxh* [mm]	Tie spacing [mm]	Number of investigated partitions	Diameter of cores [mm]						Total
					44	54	74	84	94	104	
1	Beam	300x450	300	7	11	3	7	6	4	-	31
2	Column	300x400	120/200	7	6	3	2	4	-	1	16
3	Beam	300x400	290	4	12	5	3	4	1	4	29
4	Column	300x400	150	8	6	5	5	4	-	5	25
5	Column	300x400	290	6	9	8	4	3	-	5	29
6	Column	300x400	300	8	16	14	7	9	-	10	56
7	Column	300x400	140	12	3	10	6	6	-	-	25
8	Column	300x400	120	7	8	3	4	4	-	2	21
Total					71	51	38	40	5	27	232

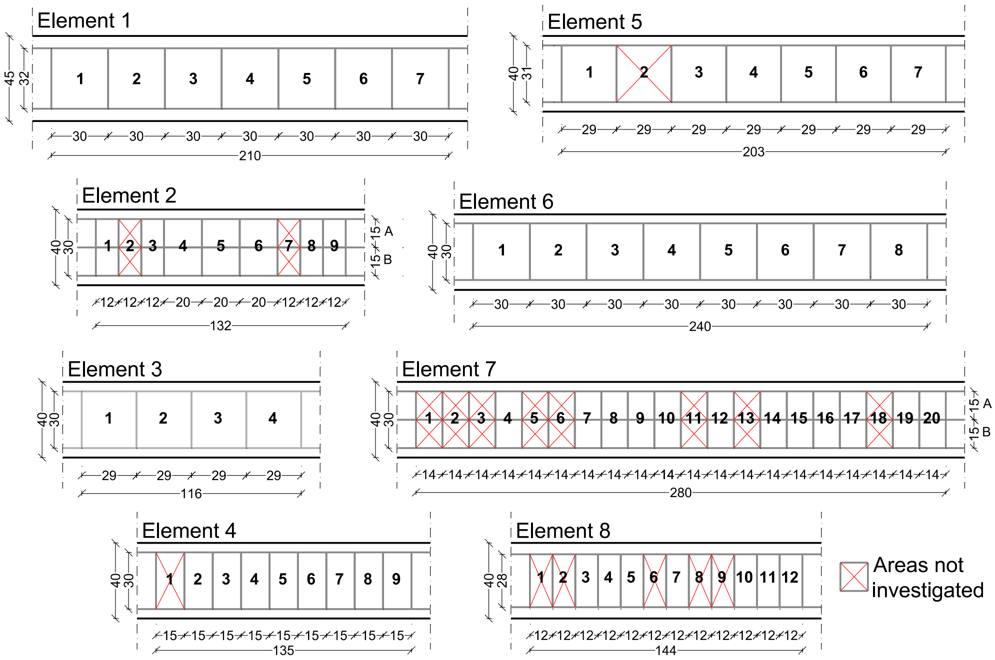

Fig. 2. Geometrical characteristics and partitions of the investigated structural elements.

2.1. Compression tests

The uniaxial compression tests allowed obtaining strength of each core (f_{core}). As is known, this value is not representative of the in-situ strength, since it is affected by a number of factors mainly connected to the specimen geometry and methods for extracting cores. There are several formulations in literature that allow estimating the in-situ strength from the laboratory strength, given by international standards (BS 6089, 2010; ACI 214.4R-03, 2003) and others available in several research works (Masi, 2007; Pucinotti, 2013; Cristofaro et al., 2017). However, for the elaborations developed in this work, it was decided to use the laboratory strength f_{core} only. The results of compression tests are shown in Table 2 and Figure 3.

Table 2. Main statistical values associated to compression tests on cores.

	Diameter of cores [mm]					
	44	54	74	84	94	104
Number of cores	32	51	39	39	5	15
$f_{core,m}$ [MPa]	34.99	37.59	36.91	38.31	44.50	35.17
St. Dev. [MPa]	9.72	7.25	5.13	7.21	5.81	7.42
CV	0.28	0.19	0.14	0.19	0.13	0.21

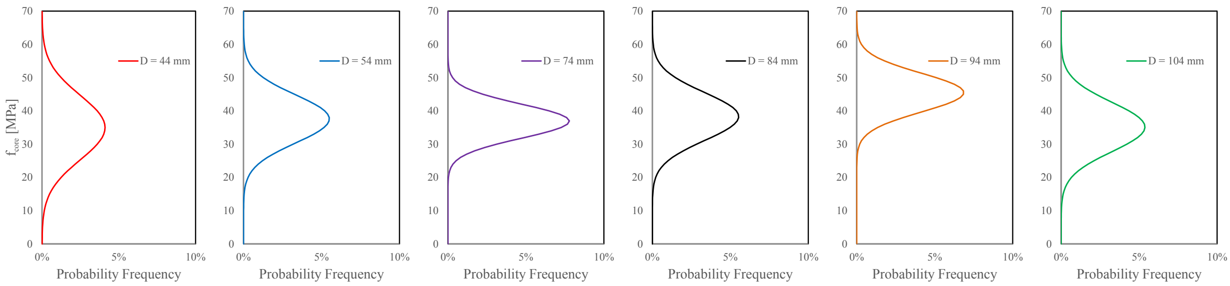

Fig. 3. Statistical distributions of compression strength f_{core} for each core diameter.

Starting from the laboratory strength f_{core}, the characteristic core strength $f_{ck,core}$ was also evaluated, through the procedure of the EN 13791 (2007) based on the following approach.

- Number of available specimens $n \geq 15$

In this case, the estimated characteristic compressive strength is given by:

$$f_{ck,core} = \min \begin{cases} f_{core,m} - k\,s \\ f_{core,l} + 4\ [\mathrm{MPa}] \end{cases} \tag{1a}$$

where:
$f_{core,m}$ is the mean compressive strength of n specimens; $f_{core,l}$ is the lowest compressive strength; s is the standard deviation of the test results or 2.0 MPa, whichever is the higher value; k is a value given in national provisions or, if no value is available, taken as 1.48.

- Number of available specimens $3 \leq n \leq 14$

In this case, the estimated characteristic compressive strength is given by:

$$f_{ck,core} = \min \begin{cases} f_{core,m} - k \\ f_{core,l} + 4\ [\mathrm{MPa}] \end{cases} \tag{1b}$$

k depending on the number n of test results, as follows:

$$k = \begin{cases} 7 & \text{for } 3 \le n \le 6 \\ 6 & \text{for } 7 \le n \le 9 \\ 5 & \text{for } 10 \le n \le 14 \end{cases} \tag{1c}$$

Values of characteristic compressive strength, for each diameter, are reported in Table 3.

Table 3. Characteristic compressive strength of cores.

	Diameter of cores [mm]					
	44	54	74	84	94	104
Number of cores	32	51	39	39	5	15
$f_{ck,core}$ [MPa]	25.36	28.00	29.40	30.02	37.50	30.81

2.2. Tensile tests

After preparation of specimens for the execution of compression tests, a significant number of core segments, of different sizes, were obtained; they were used to prepare specimens (324 in total) for the splitting test according to provisions of the UNI EN 12390-6 (2010) standards.

The tensile strength of each specimen was calculated according to the formula:

$$f_{ct} = 2F/\pi LD \tag{2}$$

being F the ultimate load, L the length of the contact lines between the specimen and the plates of the test machine (L is assumed equal to the length of the specimen) and D the core diameter. Table 4 shows the statistical values relating to the splitting tests, as a function of the core diameter; Figure 4 shows statistical distributions for each diameter of specimens.

Table 4. Main statistical values associated to splitting tests on cores.

	Diameter of cores [mm]					
	44	54	74	84	94	104
Number of cores	44	97	72	73	10	28
$f_{ct,m}$ [MPa]	4.69	4.66	3.93	3.71	3.81	3.86
St. Dev. [MPa]	1.43	0.87	0.64	0.75	0.56	0.78
CV	0.31	0.19	0.16	0.20	0.15	0.20

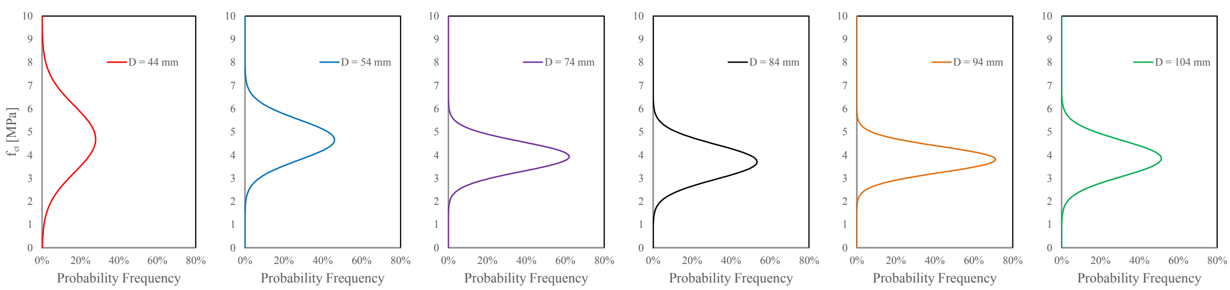

Fig. 4. Statistical distributions of tensile splitting strength f_{ct} for each core diameter.

For the purposes of the investigation, in addition to the influence of diameter, other dimensional factors were studied, such as ratios $\alpha=D/L$ and $d_{max,a}/D$, being $d_{max,a}$ the maximum aggregate size. The obtained results are shown in Tables 5 and 6 and in Figures 5 and 6.

Table 5. Main statistical values relating to the influence of ratio $\alpha=D/L$.

	$\alpha = D/L$					
	< 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0	2.0 - 3.0	> 3.0
Number of cores	7	157	83	33	37	7
$f_{ct,m}$ [MPa]	5.31	4.53	3.80	3.91	3.69	4.05
St. Dev. [MPa]	1.68	1.00	0.73	0.75	0.70	0.73
CV	0.32	0.22	0.19	0.19	0.19	0.18

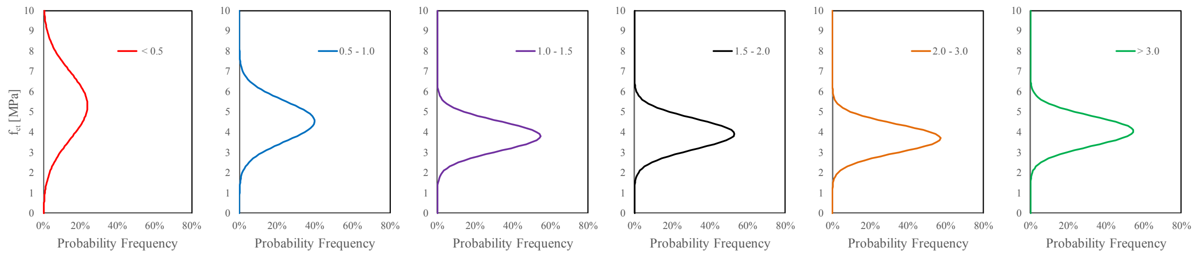

Fig. 5. Statistical distributions of tensile strength f_{ct} as a function of the ratio α.

Table 6. Main statistical values relating to the influence of ratio $d_{max,a}/D$.

	$d_{max,a}/D$				
	< 1.5	1.5 - 2.0	2.0 - 2.5	2.5 - 3.0	> 3.0
Number of cores	12	61	103	68	80
$f_{ct,m}$ [MPa]	4.54	4.35	4.39	3.96	3.95
St. Dev. [MPa]	1.15	1.13	1.08	0.80	0.68
CV	0.25	0.26	0.25	0.20	0.17

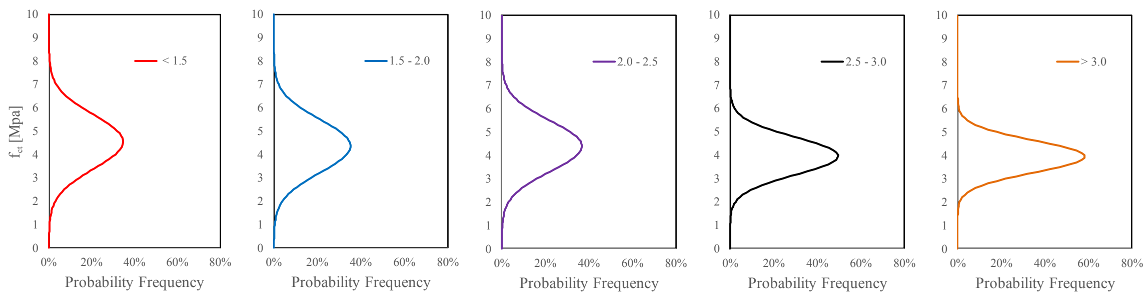

Fig. 6. Statistical distributions of tensile strength f_{ct} as a function of the ratio $d_{max,a}/D$.

In addition to the values of f_{ct} calculated according to Eq. (2), the following formulations were considered for the evaluation of a "corrected" tensile strength (Rocco, 2001; ASTM C496-90, 1991; BS 1881-117, 1983), together with the expression given by the current Italian Technical Code (Min. Infr. - NTC8, 2008).

$$f_{ctm,NTC8} = 0.3 f_{ck,core}^{2/3} \tag{3}$$

$$f_{st,c} = f_{ct}\left(1-\beta^2\right)^{3/2} \quad (4)$$

$$f_{st,ASTM} = \frac{f_t}{-7.215+4130/l_{ch1}} + 1.0238 f_{ct} \quad (5)$$

$$f_{st,BS} = \frac{f_t}{-19.302+10592/l_{ch1}} + 1.0066 f_{ct} \quad (6)$$

being $\beta=b/D$, with b the width of bearing strips used for the splitting test, equal to 10 mm for all core diameters; l_{ch1} is the reduced characteristic length (Rocco, 2001). The influence of parameters α and $d_{max,a}/D$ on tensile strength f_{ct} is illustrated in Figure 7a, b; Figure 8 illustrates the influence of the parameter β. In Table 7, different values of tensile strength calculated with the adopted formulations are compared to laboratory results f_{ct}.

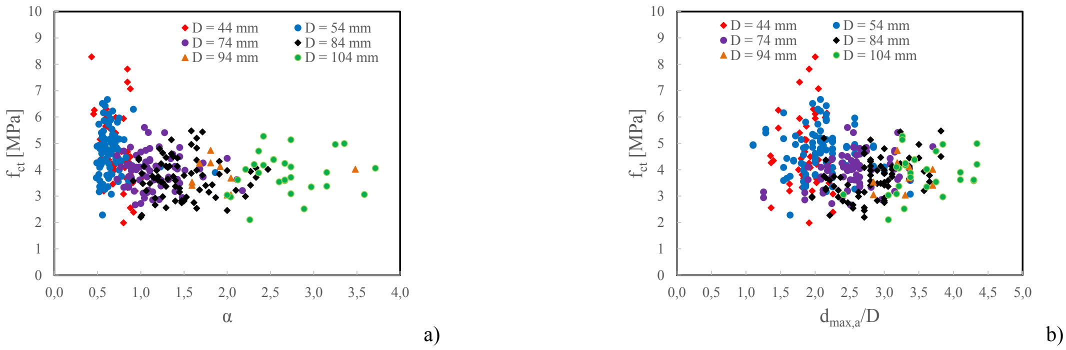

Fig. 7. Influence of parameters α and $d_{max,a}/D$ on tensile strength f_{ct}.

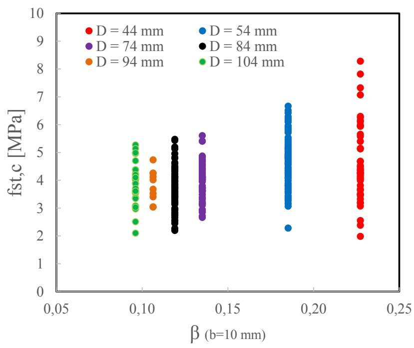

Fig. 8. Influence of the parameter β on tensile strength f_{ct}.

Table 7. Different values of tensile strength compared to the laboratory strength (medium values).

	Diameter of cores [mm]					
	44	54	74	84	94	104
$f_{ct,m}$ [MPa]	4.69	4.66	3.93	3.71	3.81	3.86
$f_{ctm,NTC8}$ [MPa]	2.59	2.77	2.86	2.90	3.36	2.95
$f_{stm,c}$ [MPa]	5.08	4.91	4.04	3.79	3.87	3.91
$f_{stm,ASTM}$ [MPa]	5.58	5.46	4.60	4.32	4.36	4.56
$f_{stm,BS}$ [MPa]	5.04	4.97	4.20	3.95	4.02	4.13

3. Conclusions

This paper deals with mechanical characterization of concrete belonging to a school building constructed in Tuscany (Italy) in the 1970s. In particular, 232 cores were extracted from the structures (beams and columns) of the investigated building, with diameters ranging from 44 to 104 mm. Each core allowed to obtain two or three specimens for laboratory tests: 181 specimens were subjected to axial compression, 324 specimens were used for the tensile splitting tests.

Results of compression tests pointed out very similar strength values, slightly dependent on diameter. A greater dispersion was found in the case of lower diameters (CV ranging from 13% to 28%). Results from splitting tests also provided similar values of strength, between 3.71 MPa and 4.69 MPa, with higher values for small diameters (D = 44 mm and 54 mm). A more marked dispersion was detected for smaller diameters (CV between 15% and 31%). Concerning the f_{core}/f_{ct} ratio, values between about 8 and 12 were obtained.

The influence exerted on tensile splitting strength by some dimensional factors, such as the *D/L* (diameter/length) and the $d_{max,a}/D$ ($d_{max,a}$ = maximum aggregate size) ratios, was also studied. In particular, it was proved that a higher strength corresponds to the lower values of the *D/L* ratio; concerning the influence of the aggregate dimensions, it was found that, as for *D/L*, smaller ratios provide higher strength, with a higher dispersion.

Some formulations, present in the literature, for correction of tensile strength obtained from the splitting test were also examined. In particular, the influence exerted by the *b/D* factor was studied, being *b* the width of the bearing strip used during the test. It was found that the proposed formulation gives a very different increase in strength depending on the core diameter (increases of 8% for *D* = 44 mm, of about 1% for *D* = 104 mm).

Finally, formulations proposed by ASTM and BS standards for estimating tensile strength from results of splitting test were also examined. The formulation by ASTM pointed out considerable strength increases, between 14% and 19%, higher for lower diameters. The formulation proposed by BS, on the other hand, provided lower increases in strength, but more uniform among different diameters (between 5% and 7%).

In conclusion, it is considered that an investigation extended to different case studies is needed, concerning more varied situations, in particular as regard the concrete age and the environmental conditions.

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