Determination of Mechanical Properties of Concrete by Destructive and Non-Destructive Experimental Methods

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Abstract

This paper examines the mechanical quality differences of concrete by destructive and non-destructive methods according to shape, dimension relationship and cure conditions. Within destructive methods, (compression, tension, bending) different shaped-sized concretes and 28-days-old concrete shear wall samples tested along to find modulus of elasticity. Non-destructive methods (ultrasonic pulse velocity test, rebound hammer test) applied same samples along to determine compressive strength and longitudinal wave velocity to obtain result of modulus of elasticity. The aim was to achieve data from applied laboratory test results and cross-checking, all values to enhance concretes compressive strength for potential possibilities.

Keywords: *Mechanical properties; Modulus of elasticity; Concrete*

1. Introduction

Destructive and Non-Destructive methods are well known and widely applied methodologies, focusing on mechanical properties of concrete. Specifically, criterias related with laboratory conditions and construction field conditions are affecting the both destructive and non–destructive methods results and application type. Most concrete structural members experience combined loading conditions composed of compression, tension, moment and shear. Especially, in the case of reinforced concrete members, the fundamental idea of concrete resisting compressive stress and steel resisting tensile stress is the basic foundation of reinforced concrete structural design [1]. According to these reasons, specimen sizes and shapes get important role on finding out mechanical properties by destructive and non-destructive methods. Gonnerman experimentally showed that the ratio of the compressive failure stress to the compressive strength decreases as the specimen size increases. This phenomenon of reduction in strength dependent on specimen is called “reduction phenomenon” [1-2]. Within the reduction, cure conditions are another endeavor for researchers before application of destructive and non-destructive tests. The focus of this study is to obtain mechanical properties such as; compressive strength, tension strength and modulus of elasticity of specified concrete specimens by destructive and non-destructive testing methods. Compressive strength of concrete can be mainly classified in to two groups as; pure axial compressive strength and SONREB based compressive strength.

2. Experimental section and methods

2.1. Materials and specimen preparation

A 1200mm x 1000mm x 200mm dimensioned shear wall shown in Fig.1 produced by C 25 quality concrete. Within same fresh concrete, twelve 100mm x 100mm cubic, twelve 150mm x 150mm cubic, twelve 100mm/200mm cylindrical and six 150mm/300mm cylindrical specimens had taken and denoted as different groups to starting curing period.

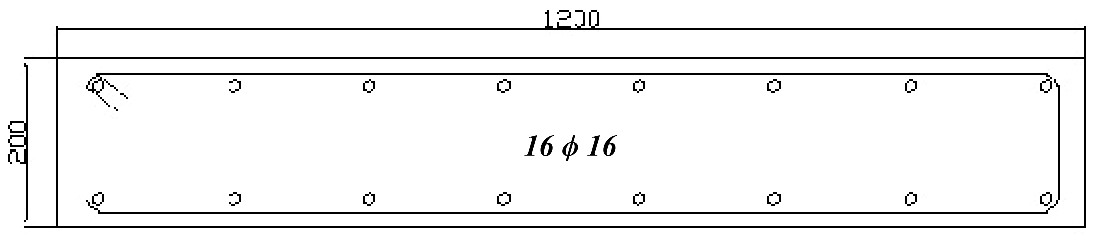

Fig. 1. Cross section of 1200mm x 1000mm x 200mm dimensioned concrete shear wall.

2.2. Measurements

At the end of the 14th day, three specimens from each shapes and dimensions had tested by destructive and non-destructive methods. By destructive methods uni-axial compression test applied for all specimens through to finding compression strength. Before destructive methods, ultrasonic pulse velocity test and Schmidt hammer rebound test applied as non-destructive methods for finding ultrasonic pulse velocity and rebound numbers of 14 days old specimens. The rest of specimens tested at the end of 28th day. Same destructive and non-destructive tests had applied again in same conditions and same theoretical techniques. Also for destructive testing methods, tensile strength test and comparator axial method had applied for obtaining datas as tension strength and modulus of elasticity for 28 days old 100mm/200mm cylindrical specimens.

3. Results and modeling

3.1. Destructive methods

Destructive methods results are summarized under 3 different categories as; compressive strength test results, comparator axial deformation test results and tensile deformation test results. Each category summarized according to age and dimensional factors.

3.1.1. Compressive strength

The experimental results of compressive strength of five different sized and shaped specimens after 14 days end and 28 days end are summarized in Fig. 2a-b. Each point indicates the different no of specimen. Three specimens used in mentioned sizes for 14 days end results. Nine cubic specimens used both100mm x 100mm and 150mm x 150mm and three specimens used for other cylindrical sizes for 28 days end results. (For 14 and 28 days old all dimensioned specimens compressive test results, see appendix A.) It is generally observed that; compression strength decreases as size of specimens increase along their shape orientation. The age factor is also another effect in strength increase. The compressive strength increases as the age of specimen gets older.

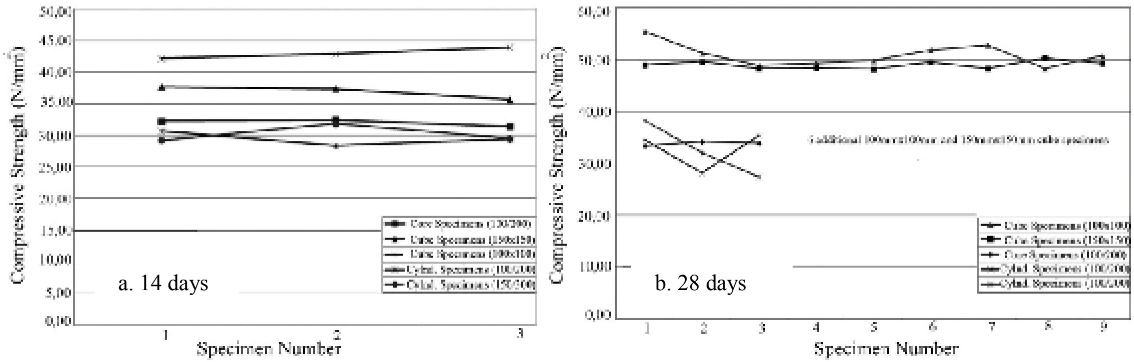

Fig. 2. Compression test results of specimens at various ages: (a) 14 days (b) 28 days.

3.1.2. Comparator axial deformation

Six 100mm/200mm cylindrical specimens, three core and three cured used in comparator axial deformation test according to obtain modulus of elasticity at 28 days end. In order to estimate modulus of elasticity, least square methods applied by following empirical equation:

$$E = \frac{\sum_{i=1}^{n} \sigma_i \alpha_i}{\sum_{i=1}^{n} \alpha_i^2} \tag{1}$$

where E is the modulus of elasticity (GPa), σ is the compressive strength (N/mm^2) and α is the correction factor of specimen under the test machine is under rate of 0,2. Theoretical lengths of the specimens are shortened 96 mm out of 100 mm original lengths before applying comparator deformation test. Results are summarized in Fig. 3a-b.

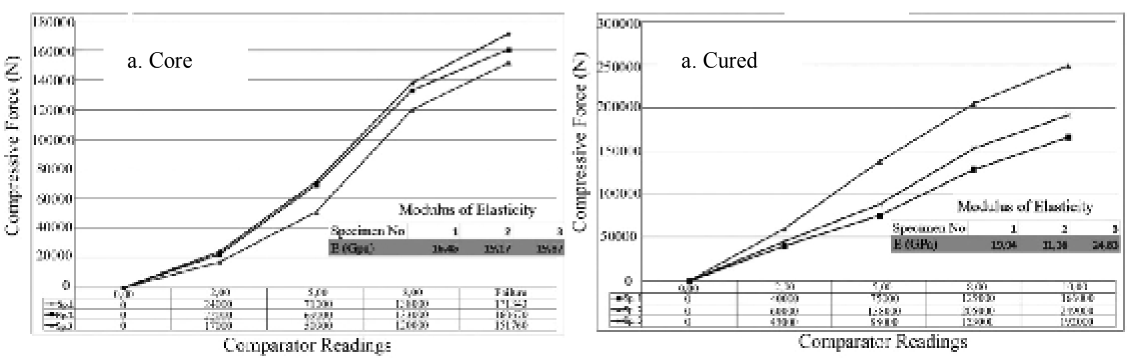

Fig. 3. Comparator test results of cylindrical 100mm/200mm core and cured specimens: (a) Core (b) Cured.

It is observed that, higher modulus of elasticity can be succeeded in cure conditions rather than core specimens.

3.1.3. Tensile deformation

In order to applying tensile deformation test, same specimen shapes and sizes are used as in comparator axial deformation test. Tensile stresses are calculated by following empirical equation:

$$f_y - \frac{P}{\frac{\pi DL}{2}} \qquad (2)$$

where f_y is the tensile strength (GPa), P is the tensile force (kN), D is the diameter of specimen and L is the length of specimen. Results are summarized in Fig. 4.

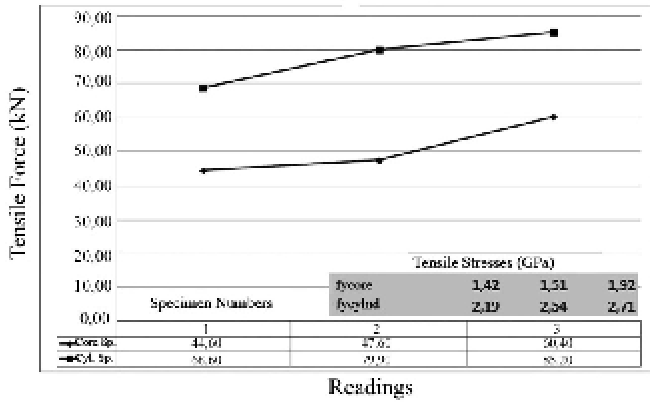

Fig. 4. Tensile deformation test results of 28 days old cylindrical 100mm/200mm core and cured specimens.

Experimental results showed that, cured cylindrical specimens obtain more tensile stress comparing with core specimens at the end of 28 days period.

3.2. Non-destructive methods

Non-destructive methods categorized under two different topics as ultrasonic pulse velocity test and SONREB method. Each method applied to all shaped and sized specimens before destructive methods. SONREB method contains a data composition of ultrasonic pulse velocity and rebound hammer test results. Categories summarized under the age and dimensional factors.

3.2.1. Ultrasonic pulse velocity

Five different 28 days old shaped and sized specimens used in application of ultrasonic pulse velocity test. Nine different specimens used in all dimensions except three 150mm/300mm cylindrical specimens. The experimental results summarized in Table 1a-e. Pulse velocities are calculated according to specimen's theoretical lengths. In order to obtain velocities, reaching period of wave lengths to other direction represents important role in determining ultrasonic pulse velocities. Empirical equation can be expressed by:

$$L = Vt \qquad (3)$$

where L(mm) is the specimen length, V(km/s) is the ultrasonic pulse velocity and t(μs) is the reaching period of wave lengths. After obtaining results of pulse velocity test, Sullivan's ultrasonic pulse velocity-compressive strength correlation chart [3] had used for determining compressive strength of specimens (See appendix B). Without calculating compressive strength, with Whitehurst's chart [4], it is also possible to get an opinion about concretes quality in Table 2. According to Whitehurst's chart, the reaching ultrasonic wave velocities related with the concretes granulometric density. If the velocity increases, quality of concrete increases directly.

Table 1a. Ultrasonic pulse velocity test results of 28 days old core specimens (100mm/200mm).

Specimen No	1	2	3	4	5	6	7	8	9
t(μs)	46,60	46,00	47,30	47,20	46,50	48,70	47,00	48,40	49,20
v(km/s)	4,29	4,35	4,23	4,24	4,30	4,11	4,25	4,13	4,07

Table 1b. Ultrasonic pulse velocity test results of 28 days old cylindrical specimens (100mm/200mm).

Specimen No	1	2	3	4	5	6	7	8	9
t(μs)	43,60	45,00	44,40	43,10	44,20	43,60	43,80	45,20	43,90
v(km/s)	4,59	4,44	4,50	4,64	4,52	4,59	4,57	4,42	4,56

Table 1c. Ultrasonic pulse velocity test results of 28 days old cube specimens (100mm x 100mm).

Specimen No	1	2	3	4	5	6	7	8	9
t(μs)	23,90	24,10	24,20	23,20	24,20	23,70	24,10	23,60	23,50
v(km/s)	4,18	4,15	4,13	4,31	4,13	4,22	4,15	4,24	4,26

Table 1d. Ultrasonic pulse velocity test results of 28 days old cube specimens (150mm x 150mm).

Specimen No	1	2	3	4	5	6	7	8	9
t(μs)	35,60	37,00	35,80	35,40	35,30	33,80	34,30	34,10	36,20
v(km/s)	4,21	4,05	4,19	4,24	4,25	4,44	4,37	4,40	4,14

Table 1e. Ultrasonic pulse velocity test results of 28 days old cylindrical specimens (150mm/300mm).

Specimen No	1	2	3
t(μs)	65,60	64,20	64,30
v(km/s)	4,57	4,67	4,67

Table 1. Ultrasonic pulse velocity results of 28 days old specimens.

It is generally observed as like, destructive compressive test results, cured specimens at the 28 days end period gain more compressive strength compared core specimens.

Ultrasonic Pulse Velocity (m/s)	Quality of Concrete
>4500	Excellent
3500 - 4500	Good
3000 - 3500	Suspicious
2500 - 3000	Weak
<2500	Very Weak

Table 2. Whitehurst chart (1951)

Ultrasonic pulse velocity test had given also results of day effect similarly like destructive compressive test results. At the 14 days end periods core specimens are weaker rather than 28 days old core specimens (See appendix C).

3.2.2. SONREB combined method

SONREB combined method had applied three core cylindrical specimens with dimensions 100mm/200mm of 14 days old with using both rebound hammer test and ultrasonic pulse velocity test methods. The results of experiment summarized in Table 3.

Parameters		C1	C2	C3
R Rebound Number	R_{max}	38	36	38
	R_{min}	31	32	30
	R_{avr}	34	34	34
V (km/s) Pulse Velocity	V_{max}	3,94	3,86	3,98
	V_{min}	3,92	3,80	3,98
	V_{avr}	3,93	3,83	3,98
Compressive Strength	f_{teo} (N/mm^2)	24,06	23,01	24,60

Table 3. Schmidth hammer rebound, ultrasonic pulse velocity and combined SONREB tests results of 14 days old specimens

Theoretical compressive strength obtained due to following empirical equation [5]:

$$1{,}15e^{0{,}038R+0{,}445V} \quad (4)$$

where R is the average rebound number, V(km/s) is the ultrasonic pulse velocity. Results indicated that, compressive strength of 14 days old core specimens in destructive compressive strength test results had given more increased strength comparing with SONREB combined non-destructive test results.

4. Conclusions

From studies for destructive and non-destructive methods on mechanical properties of concrete, the following conclusions are obtained;

1) In general cases, destructive methods are safer comparing along non-destructive methods.
2) Shape and size effect is also another important point during application of destructive and non-destructive methods.
3) As the specimen size increases, compressive strength of specimen decreases in both cube and cylindrical shape.
4) Both methods had given same results that, cured specimens strengths are higher than construction field specimens.
5) SONREB method gives safer results, beyond to applying ultrasonic pulse method and Schmidth hammer rebound test separately.
6) Age effect had given same results for both destructive and non-destructive methods as increased mechanical properties.
7) Modulus of elasticities and tensile strengths found by destructive methods are more appropriate for designing process of concrete compared with non-destructive methods.

Acknowledgments

This research was made at Istanbul Kültür University Materials Laboratory under the course named Final Project in 2012 spring academic year. Prof. Dr. Y. H. Önen, Assist. Prof. Dr. H. Biricik and IKU Materials R&D staffs are gratefully acknowledged.

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Appendices

Appendix A

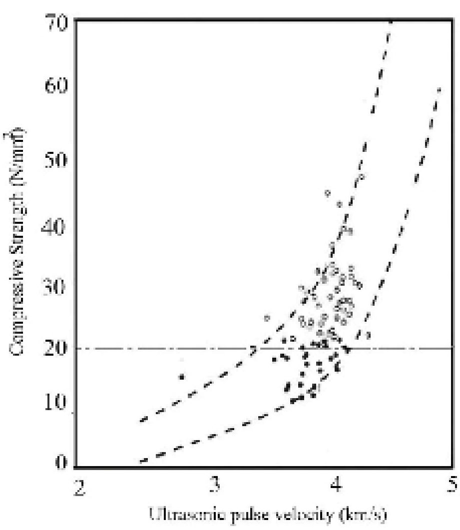
14 days old specimens' compressive strength test results (N/mm^2)

Core Specimens (100/200)	32,29	32,47	31,41
Cube Specimens (150x150)	37,74	37,39	35,68
Cube Specimens (100x100)	42,19	42,93	44,03
Cylnd. Specimens (100/200)	30,70	28,37	29,39
Cylnd. Specimens (150/300)	29,23	31,85	29,54

28 days old specimens' compressive strength test results (N/mm^2)

Cube Specimens (100x100)	55,52	51,30	48,91	49,42	49,90	51,93	52,87	48,85	50,76
Cube Specimens (150x150)	49,00	49,70	48,35	48,45	48,26	49,56	48,34	50,42	49,35
Core Specimens (100/200)	33,41	34,22	33,90						
Cylnd. Specimens (100/200)	34,56	28,10	35,39						
Cylnd. Specimens (100/200)	38,35	32,08	27,37						

Appendix B



Appendix C

14 days old core specimens

SpecimenNo	C1	C2	C3
t(µs)	50,90	52,20	50,20
v(km/s)	3,93	3,83	3,98

28 days old core specimens

SpecimenNo	C4	C5	C6
t(µs)	46,60	46,00	47,30
v(km/s)	4,29	4,35	4,23