INVESTIGATING AN APPROACH FOR DETERMINING HARDENED CONCRETE STRENGTH, EXISTING IN STRUCTURES, WITH SUFFICIENT ACCURACY

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ABSTRACT
As known, determining concrete strength in structures is necessary in many cases as such in repairing and retrofitting studies. In this determination, the most commonly used method is, because of giving good results in comparison with the other methods, drilling core specimens in various sizes from structures and then determining their uniaxial compressive strength by using current standards. In this way, concrete class used in structure is decided by evaluating obtained findings. However, concrete classes are described as strength of standard specimens produced and kept in ideal conditions, not including reinforcement and not subjected to any load effect before. Under the circumstances, transforming core strengths to standard specimen strength is necessary and considering all parameters, affected on core strength, is inevitable. In fact, effects of reinforcement and load history on concrete strength are generally neglected while these mentioned transforms are performing. The main purpose of this proceeding is investigating effects of reinforcement and load history on core strength. This investigation is experimentally performed on cores drilled from specimens having different keeping conditions, reinforced, unreinforced, subjected to bending and central pressure in various proportions of failure load during specified periods.

KEY WORDS: Concrete strength in structure, Core, Effect of reinforcement, Load history

INTRODUCTION

It is known that determining the concrete strength, existing in reinforced concrete structures, is necessary for many cases especially repairing and retrofitting of structures, damaged by earthquakes or not damaged but not having earthquake safety. In this determination, because of being more reliable, the most common method is drilling concrete specimens in various diameter and slenderness, named as core, according to the current standards (Akça, 1991; Arıoğlü and Arıoğlü, 1998; Bahadır, 1987). After capping properly, foregoing cores are crushed under compression at laboratory and then acquired strengths are transformed to standard specimen compressive strength. Potential strength of concrete used in structure, so concrete class, is determined by evaluating these strengths with obtained findings from non-destructive methods, whose calibrations' are made according to core strengths, together (Durmuş and Durmuş, 1997; Filiz, 2006; Gözaçan, 2002). However, it is known concrete classes are determined as axial compressive strengths of specimens produced and kept in ideal conditions, unreinforced and not subjected to any load effect before.

In this respect, as mentioned above transforming core strengths to standard specimen strengths is necessary. So, in these transformations considering all factors, affected on core strengths, become unavoidable. However, effects of load history and reinforcement on concrete strength are neglected while transformations are performed (Durmuş, 1996; Durmuş, 1976; Tam *et al*., 1978). The main purpose of this paper is to investigate the effects of load history and reinforcement on concrete core strength. This investigation was carried out by experimental studies on cores, drilled from beams subjected to bending effect and standard specimens subjected to axial compression effect under loads in various levels during specified periods. These beams and standard specimens are reinforced and unreinforced and kept under different keeping conditions.

The Condıtıons Requıred Determınıng Hardened Concrete Strength ın Structure

It is known that standard specimens taken from concrete produced at construction sites, for controlling the desired strengths in designs, sometimes doesn't represent this concrete sufficiently. Because producing, moving, placing and curing of concrete at construction site aren't ideal and standard specimens are unreinforced and not subjected to any load effect before. So these cause the difference between the strengths of concrete produced at construction site and used in structures. This matter constitutes one of the basic reasons of determining hardened concrete strength in structure. The other basic reasons required this determining can be listed as following:

a) that quality control isn't made during the concrete casting,
b) that strengths of standard specimen taken from fresh concrete is smaller than foreseen strength at design,
c) that some damages occur in structure,
d) that intended use of structure is changed and/or additional floor is required,
e) That repairing and retrofitting is determined as necessary against the vertical and/or horizontal loads due to the possibility of reduced concrete strength of structure by fire, earthquake, etc.
f) The need of determining the foreseen conditions in current standards are ensured or not for concrete structures (Erdoğan, 2003; TS 10465, 1992).

Methods used for determining strength of hardened concrete in structure

It is possible to say methods used for determining strength of hardened concrete in structures are assembled in three groups as non-destructive, semi-destructive and destructive (Nevil, 1977). Manual test hammer (Schmidt hammer) and ultrasonic testing methods are classified in non-destructive, and drilling cores from hardened concrete is classified in destructive methods group. These methods are widely used in Turkey (British Standard Institution, 1983; Lewis, 1976; Yip, 1982). As mentioned above in coring method, cylindrical concrete specimens, called as core, are drilled from structure in specific diameter and slenderness with special tools, by giving minimum damage to its safety. Quality of concrete used in structure is determined by axial compression test performed on these cores. However, it is known that in practice concrete strength is defined as type of standard specimen strength (potential strength).In doing so, transforming core strengths to potential strength to determine concrete strength existing in structures is necessary. Also considering all parameters affected on core strength is inevitable for performing this transformation. The main factors affected on core strength are accepted as below:

- core diameter,
- core slenderness,
- coring direction,
- coring location,
- core cure,
- core humidity,
- core age,
- reinforcement remained in core,
- shear effect at drilling core,
- strength level of concrete that cores drilled from,
- cap quality and loading speed (Bhargava and Meininger, 1967; Peterson, 1971; Bungey, 1979).

However, it is known that elasticity module of concrete is decreasing by loading and unloading (Figure 1) and also creep and shrinkage aren't freein concrete. This case gives rise to thought that effects of load history and reinforcement should be among the factors affected on concrete strength.

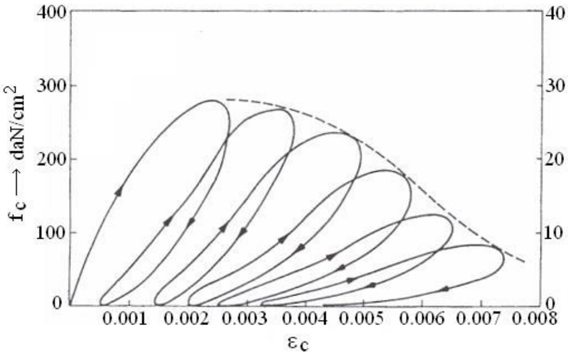

Figure 1: Behavior of Concrete under Periodic Loads (Sinha*et al.,* 1964).

Performed Studies

Shrinkage and creep actions can freely happen in standard concrete specimens because of not having reinforcement. However these actions can't happen freelyin reinforced concrete structures, so some stresses occur between concrete and reinforcement. On the other hand, standard specimens are subjected to testing before not affected by any load, whereas cores drilled from structure are remolded by remaining under some loads before subjected to testing. Under the circumstances it is thought that transforming strengths of cores drilled from structure to standard cylindrical specimen strength (potential strength) is essential. In this investigation firstly physical, petro graphical, mechanical properties and graded combination of aggregates, cement and mixing water properties, used in concrete production, concrete composition and production, properties of reinforcement used in production of specimen from which cores drilled are given. Afterwards properties, production, keeping, ages of specimens, from which cores drilled, at experiment, core drilling, experiments, results obtained from experiments and exiting conclusions and recommendations by examining these results are presented.

Physical and Mechanical Properties of Aggregates Used in Production of Concrete

Aggregates physical properties and visible sand equivalence (TS EN 1097-6/A1, 2007; TS 3529, 1980), mechanical properties and granulometric properties are presented in Table 1, Table 2 and Table 3 respectively. Petrographic texture of aggregate called as limestone was determined as limestone with cement including partly old microfossils and less than %1 opaque mineral.

Table 1. Physical Properties of Aggregate Used in Concrete Production and Visible Sand Equivalence (ESV).

Aggregate Grain Size (mm)	Loose Unit Weight (kg/m3)	Specific Weight (kg/m3)		Water Absorption (%)
		Dry	Saturated	
Coarse(>4mm)	1400	2658	2670	0,42
Fine(<4mm)	1450	2626	2640	0,52
ESV	95			

Table 2. Mechanical Properties of Aggregate Used in Concrete Production

Core Size (mmxmm)	Average Compressive Strength (MPa)	Standard Deviation (MPa)	Elasticity Module (MPa)	Poisson Ratio
75 x 150	73,4	3,2	60000	0,17
Note: Compressive strength of aggregate is determined by cores drilled from the rock that aggregate is produced to make clear fracture mechanism of concrete.				

Table 3. Graded Combination of Aggregate Used in Concrete Production

Grain classes (mm)	Percentage of total mass (%)
0,5-1,00	10
1,00-2,00	15
2,00-4,00	20
4,00-8,00	25
8,00-16,00	30

Properties of Cement and Mixing Water Used in Production of Concrete

Physical and mechanical properties of cement determined by factory, mixing water properties, concrete composition determined by absolute volume method are presented in Table 4, Table 5 and Table 6respectively (TS 802, 2009; TS EN 12390-3, 2003).

Table 4. Properties of Cement Used in Concrete Production

Physical Properties			Mechanical Properties		
Specific Weight (g/cm^{3})		3.05	Day	Bending Strength (MPa)	Compressive Strength (MPa)
Specific Surface (Blaine),cm^2/g		3285	2	3,30	15,40
Setting Time (vicat)	Starting	2,20 h	7	5,10	27,70
	Ending	3,20 h	28	6,50	35,90

Table 5. Chemical Properties of Mixing Water Used in Concrete Production

Components	Quantity (mg/l)
Na^+	50,00
K^+	0,80
Ca^{+2}	100,80
Mg^{+2}	6,72
Fe^{+3}	3,00
Cl^-	125,00

SO_4^{-2}	45,00
HCO_3^-	210,00
NO_3^-	9,50

Table 6. Concrete Composition

Water/Cement Ratio	Cement (kg/m^3)	Water (kg/m^3)	Total Aggregate (kg/m^3)	Water Saturation (kg/m^3)
0,50	350	175	1842	9,2

Table 7 Properties of Reinforcement Used in Production of Reinforced Concrete Specimens

Reinforcement Diameter	Average Yield Strength (MPa)	Average Tensile Strength (MPa)
Ø8	330	480
Ø14	406	605

Properties of Reinforcement Used in Production of Reinforced Concrete Specimens

Some of standard cube and beam specimens produced as reinforced for determining effects of reinforcement on concrete accordingly on core strength. Some mechanical properties obtained from tensile tests (TS 138 EN 10002-1, 2004) performed on reinforcement are given in Table 7. Formwork and reinforcement plan of cube and beam specimens are given in Figure 2 and Figure 3 respectively.

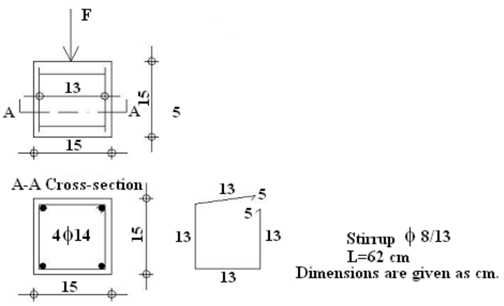

Figure 2. Formwork and Reinforcement Plan of Cube Specimens

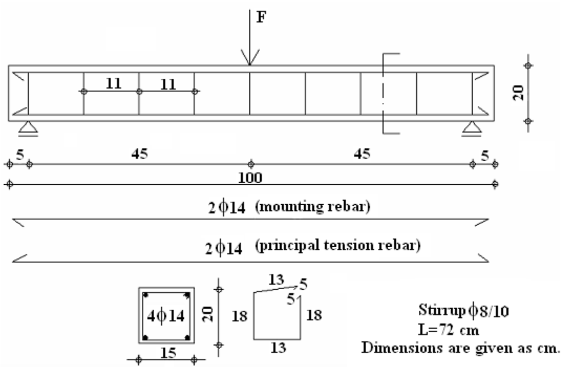

Figure 3. Formwork and Reinforcement Plan of Beam Specimens

Properties, Production, Keeping and Ages, at Experiment, of Specimens from Which Cores Were Drilled

It is thought to produce unreinforced and reinforced specimens, 75mm x 150mm, allows taking cores by not cutting reinforcements, for determining effects of load history and reinforcement on concrete strength accordingly on core strength. And also it is planned to kept these specimens in three different conditions as in water, at laboratory and at out for representing structure at construction site conditions. Concrete was casting in three phases to formworks placed on vibration table at a frequency of 2800 rpm. And in each phase concrete was compressed by vibrating for 15 seconds. Specimens were removed from formworks one day after the casting. A part of specimens was kept in water at

20°C±2°C for 27 days. Another part of specimens was firstly kept in water at 20°C±2°C for 7 days and then in laboratory at 24°C±2°C and relative humidity of %75±5 for 20 days. And the other part of specimens was kept at out of laboratory for 27 days in order to represent the concrete at construction site conditions.

Unreinforced and reinforced cube and reinforced beam specimens were subjected to loadings at specific proportions of failure loads (F_r) during specified periods (72 hours) for determining effect of load history on concrete strength. A part of unreinforced cube specimens, at 28 days, was subjected to %30 and the other part of them was subjected to %25 of failure loads, also a part of reinforced cube specimens, at 28 days, was subjected to %20 and the other part of them was subjected to %25 of failure loads for 72 hours. Failure loads at axial pressure of unreinforced cube specimens kept in water, in laboratory and at out are determined as 640kN, 600kN and 480kN respectively. Reinforced beam specimens, at 28 days, are divided four groups and these groups are subjected to %30, %40, %50 and %80 of failure loads respectively, under the effect of point load in the midpoints of beams, during 72 hours (Figure 2). Average failure loads of these reinforced beam specimens are determined as 78kN.Cores are drilled from specimen as perpendicular to concrete casting direction (TS 10465, 1992).

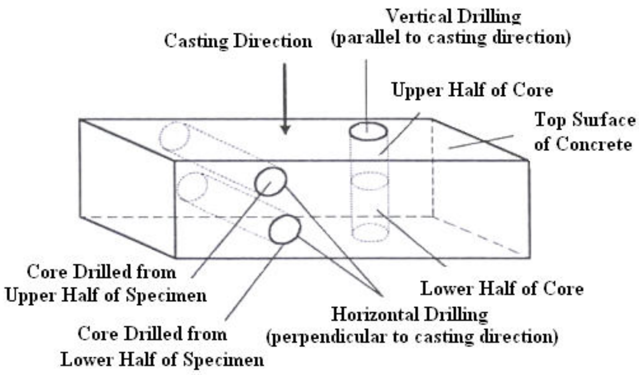

Figure 4. Directions of coring from specimen

RESULTS AND DISCUSSION

The results obtained from compression tests performed on cores, 75 mm x 150 mm, drilled from unreinforced and reinforced beam and standard cube specimens keeping at different conditions, loading at varied load levels are presented in Table 8.

Table 8. Averages Compressive Strengths of Cores, 75mmx150mm, Drilled from Reinforced and Unreinforced Cube and Beam Specimens Having Different Keeping Conditions and Load Histories.

Specimen Name	Type of Specimen from which core is drilled	Specimen Dimensions (mmxmmxmm)	Keeping Condition	Loading Level(F/Fr)	fcm (MPa)
RBW	Reinforced Beam	150x200x1000	water	unloaded	20
RBW_{30}	Reinforced Beam	150x200x1000	water	0,30	21
RBW_{50}	Reinforced Beam	150x200x1000	water	0,50	23
RBO	Reinforced Beam	150x200x1000	out	unloaded	17
RBO_{40}	Reinforced Beam	150x200x1000	out	0,40	20
RBL	Reinforced Beam	150x200x1000	laboratory	unloaded	17
RBL_{30}	Reinforced Beam	150x200x1000	laboratory	0,30	9
RBL_{50}	Reinforced Beam	150x200x1000	laboratory	0,50	16
RBL_{80}	Reinforced Beam	150x200x1000	laboratory	0,80	23
UBO	Unreinforced Beam	150x200x1000	out	unloaded	18
PBL	Unreinforced Beam	150x200x1000	laboratory	unloaded	21
RCW	Reinforced Cube	150x150x150	water	unloaded	27
RCW_{20}	Reinforced Cube	150x150x150	water	0,20	20
RCO	Reinforced Cube	150x150x150	out	unloaded	14
RCO_{20}	Reinforced Cube	150x150x150	out	0,20	15
RCL	Reinforced Cube	150x150x150	laboratory	unloaded	10
RCL_{20}	Reinforced Cube	150x150x150	laboratory	0,20	16
RCL_{25}	Reinforced Cube	150x150x150	laboratory	0,25	21
UCW	Unreinforced Cube	150x150x150	water	unloaded	34

UCW_{30}	Unreinforced Cube	150x150x150	water	0,30	27
UCO	Unreinforced cube	150x150x150	out	unloaded	20
UCO_{30}	Unreinforced Cube	150x150x150	out	0,30	23
UCL	Unreinforced cube	150x150x150	laboratory	unloaded	20
UCL_{25}	Unreinforced Cube	150x150x150	laboratory	0,25	22
UCL_{30}	Unreinforced Cube	150x150x150	laboratory	0,30	23

The Effect of Reinforcement

As seen at Table 8, average compressive strength ratio of cores drilled from reinforced cube specimens kept in water (RCW) to cores drilled from unreinforced cube specimens kept in water (UCW) is 0,79 and this ratio is 0,70 for cores kept at out (RCO, UCO). The average compressive strength ratio of cores drilled from RBW to cores drilled from UBW is 0,86and this ratio is 0,80 for cores kept at out (RBO, UBO). It is seen that strengths of cores drilled from reinforced specimens are lower than those of unreinforced specimens. It can be attributed to creep and shrinkage events not occurred in reinforcement but occurred in concrete. Because creep and shrinkage events are occurred more freely in concrete specimens than reinforced concrete specimens. Therefore damaging stresses aren't occurred between concrete and reinforcement in these specimens.

This case provides to get high strengths for these specimens. Also the difference gets bigger when keeping conditions are getting away from ideal conditions.

The Effect of Load History

Average compressive strengths of cores drilled from UCW and UCW_{30} specimens are 34MPa and 24MPa respectively. Therefore a strength reduction around %20 is occurred due to the effect of load history at this level. Core strengths are 20MPa and 23MPa respectively (PCO and PCO_{30}) when keeping condition is out. And this corresponds to a strength increase around %15. These results indicate that effect of load history on cores isn't independent from relative humidity of cores. Therefore evaluating these two factors together is necessary for determination of concrete strength used in structures. Average pressure strengths of cores drilled from RBW, RBW_{30} and RBW_{50} specimens are 20MPa, 21MPa and 24MPa respectively. This case shows that while loading level increases core strength is also increase. It is clear that when concrete behavior is considered, core strength is decreasing by load history after a particular value of loading level. Average pressure strengths of cores drilled from RCW, RCW_{20} specimens are 27MPa and 20MPa respectively.%20 axial loading level for cube specimens leads to a decreasing around %26in core strength, contrary to bending. Examining and evaluating of these results are indicate that if effects of load history and reinforcement weren't considered, transforming core strengths, drilled from hardened concrete of structures, to concrete class, used in designs, correctly wouldn't be possible.

CONCLUSION

It is known that the following factors are affected on core strengths drilled from hardened concrete of structures and thus these factors are considered for determining concrete strength.

- core diameter,
- core slenderness,
- coring direction,
- coring location,
- core cure,
- core humidity,
- core age,
- reinforcement remained in core,
- shear effect at drilling core,
- strength level of concrete that cores drilled from,
- cap quality and loading speed.

The main purpose of this paper is considering effects of load history and reinforcement in this determination. These two factors aren't usually considered or can't be considered because of not having reliable results.

Main conclusions and recommendations of this study, performed for this purpose, can be summarized in the following:

1. Reinforcement have always effect on core strength regardless of shape, sizes, loading case and keeping conditions of specimen from which cores were drilled.
2. Effect of load history is changing with relative humidity of core, loading level, loading pattern, shape and sizes of specimen, being reinforced or unreinforced and keeping conditions but it always affect on core strength.

Briefly, evaluating findings obtained from this study shows that load history and reinforcement are affects on core strength. However, it is clear that these conclusions are valid for specimens used in this study and conditions of performed study. In this regard studies on this subject can be increased for making the conclusions reliable and generalizing them. Also performing these studies under different periodic loads will be beneficial. These subjects will be able to provide more of our research.

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