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Effect of Concrete Casting Conditions on Strength of Reinforced Concrete Walls

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ABSTRACT: In this paper, quality of concrete used in reinforced concrete walls (RC-walls) in different phases from production to placing stage are studied. For this purpose, nine different RC-walls were cast which have different properties. Two different concrete classes were used in experiments. Some core specimens were drilled 14 and 28 days after the concrete is cast. Compressive test results of these core specimens are compared to control specimens which are cured in laboratory conditions. Factors such as concrete classes, mold type, placing with vibrator, curing are evaluated separately in every concrete specimen and results are discussed. It is found that compressive strength and hardness of the cores extracted from air cured RC-walls with low reinforcement bar spacing is lower than that of core specimens from RC-wall which are vibrated and wet cured specimens and have normal reinforcement bar spacing.

1. INTRODUCTION

Concrete is a structural material of which properties can be easily affected by environmental effects. Compressive strength of a ready-mixed concrete can be decreased by improper placing methods and bad environmental conditions. Mold material, using vibrator, reinforcement bar spacing and environmental conditions are important factors which affect concrete quality significantly. Even quality of a properly mixed concrete with a good mixture can be affected by various factors such improper placing and environmental conditions. Therefore, it is aimed to emphasize importance of the effects of environmental conditions to compressive strength of concrete. Ready-mixed concrete is transported to construction site with trans-mixers and placed with high-powered pumps. The concrete has an average slump of 130 mm and it should be placed to prepared molds by portable vibrators by considering reinforcement detailing in mold.

Preferred mold types vary due to contractor firms. New mould timber, used mold timber, plywood and steel mold modules can be used as molding material. With all these facts combined with environmental conditions even high strength concrete with a good mixture cannot show good performance on site. Under lateral loads such as earthquake and wind loads, structure may fail before RC elements reach to their theoretical strengths. Similar studies are made about this subject and some theses are conducted. Uysal and Yılmaz (2009) studied the effects of low reinforcement bar spacing to RC-elements cast with self compacting concrete (SCC). And it is concluded that SCC is a good solution for RC-parts which have low reinforcement bar spacing like column-beam connections. In our study more common ready-mixed concrete are examined. Topçu et al. (2008) studied the properties of SCC and examined the cases which affect compacting of the concrete. Self compacting concrete eliminates many negative factors of placing with its liquidity. Additional admixtures and additives is not a preferred option for ready mixed concrete in site and they decrease workability of concrete.

Snell and Gillespie (1970) conducted compression tests on properly cured specimens which are cast in plastic glass and cardboard molds. They found that compressive strength of concrete which is cast in plastic glass mold is higher than the concrete cast in cardboard molds by 7%. As can be seen from the results compressive strength of the concrete is slightly different for these two mold materials. Day (1994) studied effect of mold material and dimensions on concrete compressive strength. After conducted tests on 14 different specimens, he concluded that mold material is not effective on the compressive strength of concrete. Bektaş et al. (2002) studied the effect of vibration duration to compressive strength and unit weight of concrete. They prepared 40 standard cubic specimens and applied vibration by using table vibrator to these specimens and after this process they determined compressive strengths and unit weights of all specimens. They concluded that placing by vibration is important for reinforced concrete. Yılmaz and Canpolat (2002) studied the effect of vibration on concrete quality. In conclusion, compressive test results of specimens, which are cast without vibrator, are measured significantly low. Decrease rate is found nearly 35% of concrete specimens which have low slump values. Topçu and Akman (2002) studied on determining mold removal duration by maturity and found that mold removing duration changes for different climate conditions. Subaşı (2009) studied the effect of permeable mold to maturity time of concrete and they found that compressive strength of concrete is also related to mold type, and concrete compressive strength is increased by the effect of plastered surface molds.

In this paper, effect of placing method, mold type and environmental conditions on compressive strength of concrete that in both site and laboratory conditions is studied in RC-walls.

2. EXPERIMENTAL STUDY

Concrete experiments were carried out in two sub-groups as laboratory and site conditions. The component of two type of concrete groups i.e. laboratory and on-site investigations were same. The relation between the surface hardness and compressive strength of concrete is studied.

2.1. Laboratory studies

For laboratory study, cylindrical specimens (Ø150x300 mm) are prepared from concrete for determining compressive strength of the concrete. Two different concrete classes (C25/30 and C30/37) are used in experiments. Compressive strength of these specimens, which are cured in laboratory conditions, is compared to compressive strengths of other specimens. In the production of concrete batches, three types of aggregates as 0-4, 4-11.4 and 11.4-22 mm were used. CEM I 42.5R type ordinary Portland cement (OPC) was used. Its specific gravity and Blaine fineness is 3.12 and 3170 cm^2/g, respectively. Workability (slump) of used concretes was kept as constant. Components and mixture ratios of used concretes are given in Table 1.

Table 1. Concrete properties and components

Concrete Class	C 25/30	C30/37
Environment Class	XC2	XC3
Cement Type	CEM I 42.5 R	CEM I 42.5 R
W/C Ratio	0,55	0.52
Slump Value	130 mm	130 mm
Chloride Class	CI 0.20	CI 0.20
Cement, kg/m^3	310	375
Water, lt/m^3	180	185
Aggregate (0-4), kg/m^3	965	940
Aggregate (4-11.4), kg/m^3	302	277
Aggregate (11.4-22), kg/m^3	544	519
Fly Ash, kg/m^3	40	40
Air, %	1.7	1.7

2.2. On-site studies

In site investigations, plywood and standard timber are used for molding in production of RC-wall elements. Concrete placement process is carried out both with and without vibrator. In addition, specimens are divided into two groups which are wet-cured and air-cured. Same reinforcement detailing is used in the forming of RC-walls. Concretes were casted with concrete pump into RC-wall molds which have reinforcement bars with low spacing. Visual details of RC-walls can be seen in Figure 1.Core specimens are taken with core drilling machine from top (T), middle (M) and bottom (B) regions of the RC-walls, where the reinforcement spacing is low, high and low, respectively. Thus, effects of factors such reinforcement bar spacing in column, vibration, concrete compaction with its own weight are studied in the present study.

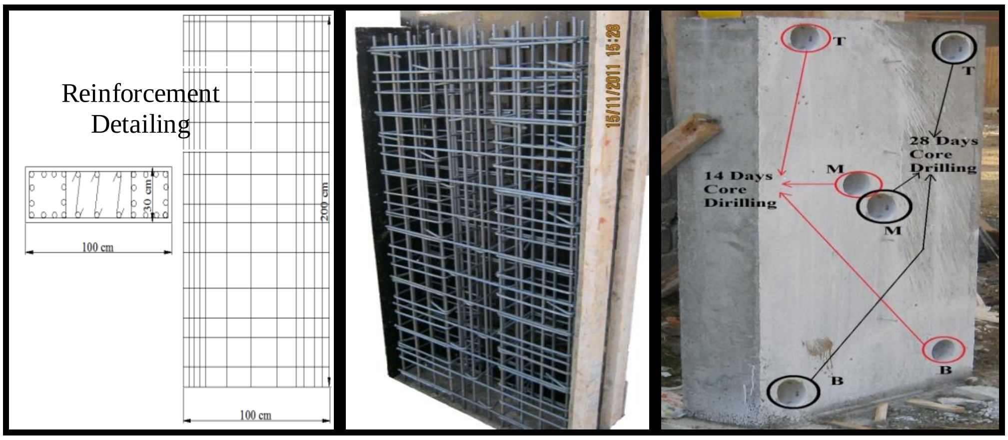

Figure 1. Reinforced concrete wall detailing

As control group, standard cylindrical specimens that in size of Ø100x200 mm were extracted. For eliminating effect of reinforcement bars to compressive strength of concrete, compressive strength values are multiplied by 1.13 in core specimens. Schmidt tests are conducted for determining surface hardness of specimens with low reinforcement bar spacing before extracting the core specimens. The readings for Schmidt hammer were carried out on 400 cm^2 wall areas for each specimen. Reinforcement detailing of the RC-elements used in experiments were the same and two different concrete classes (C25/30 and C30/37) were used. Abbreviations and properties of RC-wall elements are given in Table 2 with mold types.

Table 2. RC member properties

Series No		Mold Type		Vibration	Concrete Class		Wet-Curing	Air-Curing
		Plywood	Timber		C25/30	C30/37		
1	PVK	X		Yes		X	X	
2	PVK	X		Yes	X		X	
3	TVK		X	Yes		X	X	
4	TVK		X	Yes	X		X	
5	PK	X		No	X		X	
6	PK	X		No		X	X	
7	TK		X	No	X		X	
8	TK		X	No		X	X	
9	P	X		No		X		X

P: Plywood mold, T: Timber mold, V: Vibration, K: Proper curing

On the concrete specimens that both produced in laboratory and taken from RC-walls, compressive strength test was performed according to TS EN 12390-3 standards, respectively, by 2000 kN compression machine with a rate of loading controller. However, the results were evaluated according to TS EN 13791 standard that is related with concrete of existing structures.

3. RESULTS AND DISCUSSIONS

Compressive strength test results of RC-walls and laboratory specimens are given in Table 3 for 14th and 28thdays. As can be seen in Table 3, laboratory test result values are higher than the compressive test results of core specimens. Schmidt test result values are significantly high. Comparison graphs of 14th and 28th days compressive test results for each RC-wall depending on core region are presented in Figures 2 and 3, respectively, according to specimen code.

In Figures 2 and 3, it can be seen that compressive test results of the concrete placed with vibrator is higher than that of placed without vibrator. Strengths of core specimens taken from bottom regions of the RC-walls are slightly higher than the strength of core specimens drilled from top regions. Reason of this case is the proper placing of concrete due to its self weight.

Table 3. Compressive Strength (MPa) and Schmidt hammer test results for all RC specimens

Series No		Schmidt Test Results				Core Test Results		Control Specimen	
		In site		In laboratory		14 d	28 d		
		14 d	28 d	14 d	28 d	Avg	Avg	14 d	28 d
1	C30/37 PVK	33.00	34.83	33.86	35.68	25.11	28.04	28.44	33.87
2	C25/30 PVK	28.25	29.56	30.12	32.25	18.98	23.11	21.45	25.56
3	C30/37 TVK	33.45	35.25	35.25	37.11	25.38	28.57	28.65	32.17
4	C25/30 TVK	29.65	29.89	31.56	32.65	18.77	23.21	21.36	26.22
5	C25/30 PK	26.15	27.25	27.12	28.14	16.68	21.84	21.00	24.55
6	C30/37 PK	28.23	28.69	29.45	31.22	18.48	26.63	28.65	31.11
7	C25/30 TK	27.25	28.01	27.98	28.15	13.71	24.26	22.56	25.01
8	C30/37 TK	28.95	29.21	30.12	31.23	15.07	27.53	28.23	32.88
9	C30/37 P	25.25	26.23	27.12	28.25	13.77	16.15	27.66	31.56

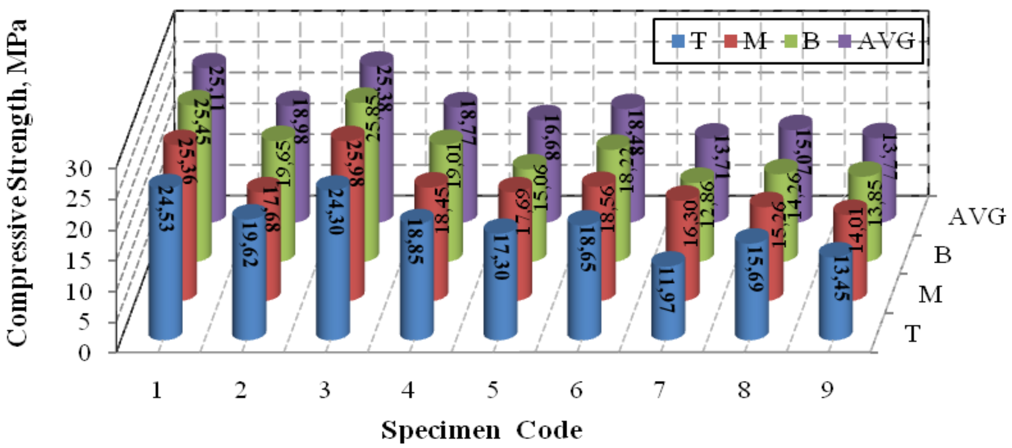

Figure 2. 14 days test results.

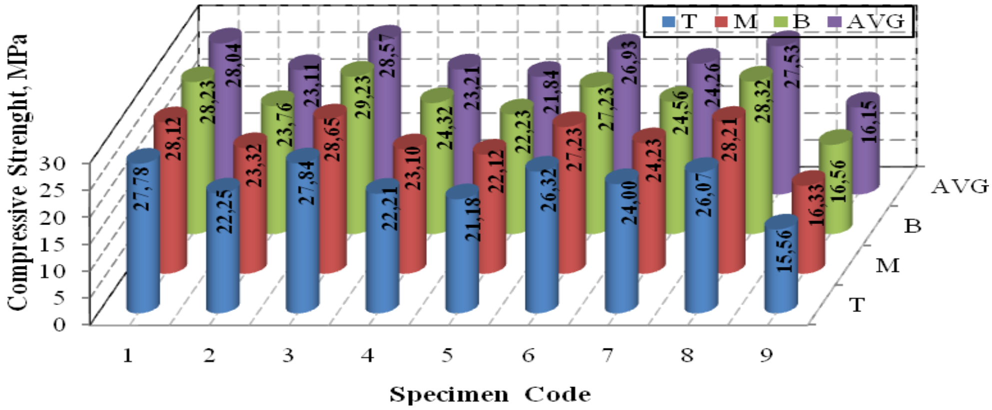

Figure 3. 28 days test results

The 14th and 28th day compressive test results of specimens, which are placed without using vibrator and air-cured, are significantly low and close to each other. The 28th day compressive test values of properly cured specimens are considerably higher than 14th day compressive strengths. The 14th and 28th day compressive strengths of the specimens, which are wet-cured and cast with using vibrator, are close to each other and similar to the results of control group.

3.1. Effect of mold type

The differences between placing the concrete into standard timber and plywood mold to core specimen strength are studied. If compressive strength of two specimens of which properties are same except their mold type is compared, it can be seen that compressive strength values are not considerably different from each other. It can be concluded that mold type is not effective on compressive strength of the concrete. However, Schmidt results should be carefully examined given in Table 3 and Figure4. As can be seen in Figure4, Schmidt results of the concrete cast in P molds are higher than the concrete cast in standard T molds (Pronk et al., 2009; Raun et al., 2010). As expected, standard T mold soaks water from concrete mixture and hardens the surface of the concrete. Therefore, Schmidt results are measured high for concretes placed in P molds.

3.2. Effect of placing with vibrator

Comparison of 1st and 6th series form the RC-wall element shows the difference between compressive strength of concretes which are placed with and without vibrator. Effect of placing with vibrator on compressive strength of concrete is presented in Table 3 and Figure 5.

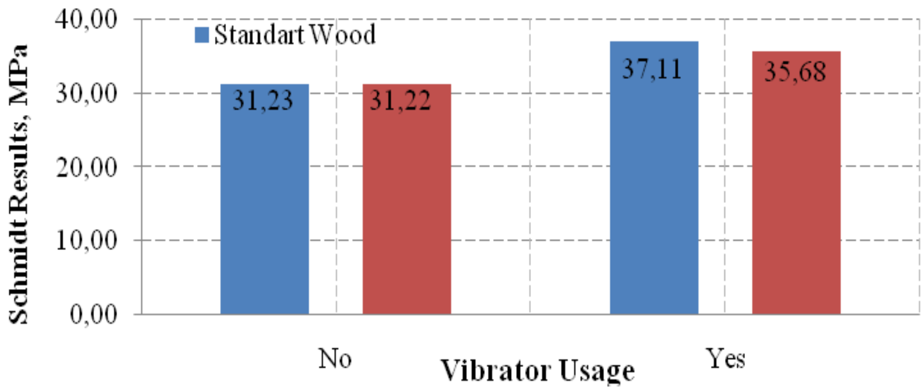

Figure 4. Mold type effect to Schmidt hammer results

Effects of vibration and curing to compressive strength of the concrete can be seen in Figure 5. Placing the concrete with vibrator is very effective on compressive strength as a reason of its compacting effect. For specimens of which mold types are the same, compressive strength values varies up to 10% due to vibrator usage. Also Schmidt test results of specimens, which are not placed with vibrator, are significantly low and it is concluded that vibration is effective on obtain the surface hardness of the concrete. It also shows the increase of compressive strength.

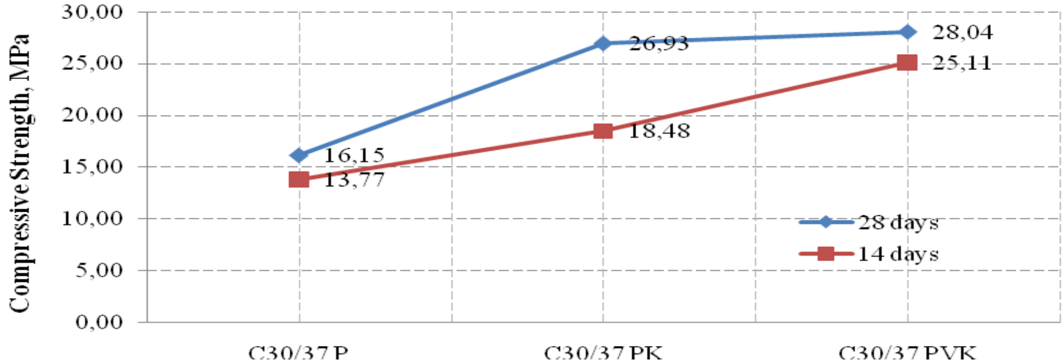

Figure 5. Effects of vibration and curing to compressive test results

3.4. Effect of curing and weather condition

If 1st experiment group C30/37 PVK (plywood mold, cast by vibration and proper curing) and 9th experiment group C30/37 P (plywood mold, no vibration, no curing) is compared 28th day compressive results of 9th group is lower than the 1st group by 42%. If Schmidt test results of 1st and 9th experiment groups are compared, it can be seen that surface hardness of 9th group is lower than surface hardness of 1st group by 25%. This result indicates the importance of vibration and curing for low slump concretes. In 6th group, mold type is plywood and specimens are cured properly, however specimens are not placed by vibrator. If this group is compared to 1st and 9th groups, compressive strength values are higher than compressive strength of 9th group by 66% and lower than 1st group by 4%. Importance of curing can be seen from this comparison. Also, curing increases surface hardness of the concrete too (Klieger, 1958). By considering recorded temperatures, it can be said that concrete was cast under bad weather conditions. Thus, compressive strength values are lower than expected. This case requires the calculation of maturity age of the concrete. If strength-maturity factor relation is examined, Maturity phenomenon is described as a function of multiplying of curing time (t) and concrete temperature (T) (Maturity = f(T*t)). If two concrete specimens, which are prepared with same materials and mixture ratios, cured in same conditions, their compressive strengths are expected to be same. However, when curing time and concrete temperature is different, rate of strength gain values will be different. The equation is presented by Nurse and Saul (Eq. 1).

$$M=\sum(T-T_o)\Delta t \qquad (1)$$

In Eq. 1, M is maturity factor (◦C. Day or ◦C. Hour), T is temperature of the concrete (◦C), T_o is datum temperature and Δt is curing time (day or hour) at T temperature. To determine the strength gain of the concrete in the structure, concrete should be cured under laboratory conditions and strength-maturity factor relation should be obtained as shown in Figure 6. From strength-maturity factor relation diagram, maturity value is determined for the compressive strength which corresponds to 70% of 28th day strength of the concrete. After this process, maturity values for certain intervals should be calculated with $M=\sum(T+10)\Delta t$ formula. Maturity factor versus strength graph of the 1st and 9th experiment groups are given in Figure 6.

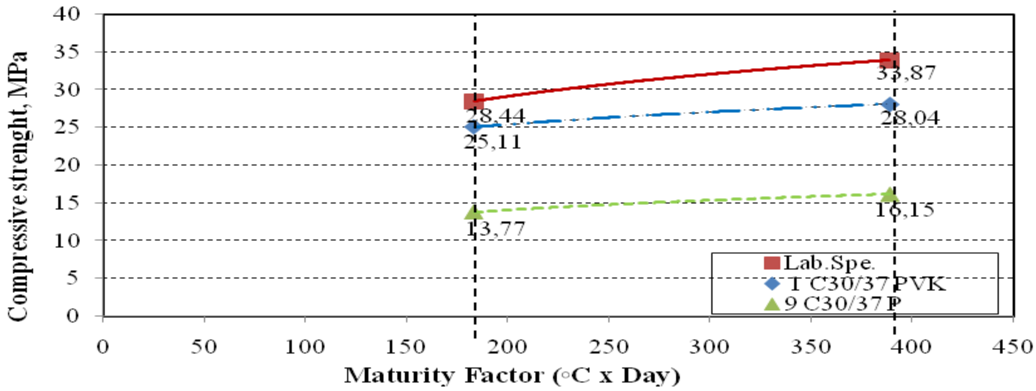

Figure 6. Maturity Factor-Compressive Strength Relation

The 14th and 28th day maturity factors of specimens are calculated by using recorded temperatures and compressive tests are conducted on specimens in 14th and 28th days. Obtained results are plotted. During experiments, weather temperature was below +5 ^{o}C. As a reason of this case concrete temperature was affected by environment temperature and concrete could not reach the expected compressive strength. This case is both observed in 1st and 9th specimen. However, differences are more significant in 9th specimen as a reason of lack of proper curing.

3.6. Effect of low reinforcement spacing

Conducted experiments indicate the importance of reinforcement spacing. Reinforcement spacing of RC-walls are designed to be low at sides and large at middle regions. Compressive strength values of the cores which are drilled from middle regions are measured higher than the cores taken from other regions because of low reinforcement spacing. Compressive strengths according to different core drilling regions are given in Table 3 depending on mold types. For workability and high strength, reinforcement bar spacing should be chosen properly in RC-elements. Absolute concrete area is found by subtracting the area of reinforcement bars from the area of complete section. The concrete-reinforcement bar adherence is lost in the core region of the RC section. A discontinuity is formed and section may experience excessive deformations. This case points out the importance of compacting of concrete when it was used in RC-wall.

4. CONCLUSIONS AND RECOMMENDATIONS

The 28th and 14th day compressive strengths of 1st (C30/37 PVK) and 3rd (C30/37 TVK) groups are similar. However, Schmidt test values of 3rd group are higher than the Schmidt test values by 4%. Strengths of specimens, which are cured in laboratory conditions, are measured higher than the specimens cured in site conditions by between 10% and 20%. Maturity, vibration, curing and reinforcement spacing are the reasons of this case. In application casting time and weather conditions should be considered. And maturity of concrete should be calculated before deciding mold removal duration. Concrete mixture and maximum aggregate dimensions should be prepared by considering reinforcement spacing. Vibration is essential for placing concrete to molds. Curing should not be neglected and concrete quality should be kept as high as possible. With all these factors combined, we cannot completely trust the calculated theoretical strength of the concrete. Not only mold type but also placing method is effective on Schmidt test results. The 14th and 28th day strengths are closer to compressive test results of the specimens cured under laboratory conditions only if weather temperature is over +5 ^{o}C. It should be placed with vibrator unless it is SCC. RC bar spacing should be considered and concrete should be placed carefully.

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