In-Situ Evaluation of Concrete Made of Slag Cement by Using Destructive and Non-Destructive Methods

Mahfuz PEKGÖZ, İyad Asri AHMED, İlker TEKİN*.

Karabük University, Faculty of Engineering, Civil Engineering Department, Karabük, Turkey

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Core strength,
Newly constructed building.

Abstract

The compressive strength of concrete could be evaluated during and after construction because of a weakness in a reinforced concrete structural member appeared. Quality control of concrete in existing and new constructions can be evaluated by several methods. If the compressive strength did not comply with the design requirements, core samples from the low strength structural members are usually taken to evaluate the structural capability. In the construction sites, compressive strengths of columns and shear walls are the most important. Also, the preparing of quite simple reports for the quality control analyses of a construction is common especially in slab and beam analyses. Hence, in this paper, a new sightseeing assessment is recommended to this analysis. In this study, in-situ non-destructive and destructive investigations in newly constructed building slabs and beams were performed because of the weakness of concrete. With this scope, non-destructive and core sampling examinations were performed on slabs and beams according to the TS EN 13791. Building was constructed by using ready-mixed concrete with CEM I 42.5R and CEM II/B-S 42.5N type cement. As a result of this study, it is thought that the TS EN 13791 contains limited information for the evaluation of newly constructed building for concrete because of its varied ingredients. Compressive strength of concrete produced with granulated blast furnace slag like pozzolanic materials instead of cement needs more time to reach required strength if it is not designed for early strength.

1. Introduction

The compressive strength is the major property of structural concretes because of reinforced concrete design parameters. As it is well-known that the components and mix design of concrete affect the concrete strength significantly. Thus, well-designed mixing and the selection of appropriate materials are not only significant parameters in structural concretes but curing regime and good workability also important. However, because the concrete sector is extremely competitive in general, and companies often utilize a limited budget for mix design, many companies can produce inappropriate concrete. Besides, to obtain the requested concrete strength with proper workability in the laboratory, a lab technician must examine a few mix proportions to ensure concrete capability. This can be a time-consuming procedure and can increase waste material, leading to an increase in concrete production cost [1]. Thus, the commitment to the codes and standards' must be applied in the concrete mix design and production. However, the valid empiric equations presented in standards for guessing the concrete strength are based on concrete tests without linking supplementary cementation material (SCM). Therefore, it is significant to research the currency of these relations for concrete that contains SCM [2].

For many years, slag has been utilized as a supplementary cementitious material in Portland cement concretes, both as a mineral admixture and cement component [3]. Slag is a byproduct material produced from the glassy granulated material created when molten slag is speedily cooled by submerging it into water [4,5]. Slag can replace 35–65% of Portland cement in concrete. The employment of Slag as a partial replacement of OPC develops the strength and durability of concrete by creating an intensive matrix and boost the service life of concrete structures [6]. However, the incorporation of slag can decrease the early strength of concrete; simultaneously, this incorporation leads to an effective increase in the strength at late ages [7]. And increasing the amount of slags in the concrete mix in general lead to an increase in the strength of concrete [8]. Furthermore, concrete made with slag, both as a replacement for cement and as a mineral admixture, has numerous advantages such as: improving long-term strength and durability, increasing the

workability, decreased the porosity and alkali-silica expansion and economic benefits [9–11].

There are three methods to determine the in-situ concrete compressive strength the destructive method, the non-destructive method and using both together. Concrete coring is applied as a destructive test, while the Schmidt hammer (SH) test is a non-destructive [12]. Today, concrete coring is widely used to determine the concrete quality and concrete strength if the hardened concrete compressive test results were obtained a lower value than the design parameters. However, this coring leads to a high-cost process [13]. Moreover, since the core sampling could affect the existing structure (especially for building type structures) and leave holes in it, this method should be the last choice, and it should be done under the supervision of a civil engineer [14]. The SH test method's major advantage is that it does not damage or influence the building's structural performance. In addition, it can reveal new information regarding the properties of concrete and identify the homogeneous areas [15, 16]. The SH test offers simplicity and rapidness in use, and the test results are immediately present on the site. Moreover, the applied testing equipment is both less expensive, and there is a facility of testing concrete strength in structures where cores cannot be drilled (thin walls, densely reinforced, etc.). This also reduces labor consumption of testing and preparative work, such as tedious work associated with determining the location and diameters of reinforcement bars. However, SH results do not reliable if it is used as single equipment for later ages [17]. The SH device producer generally provides details of the empiric relation between concrete compressive strength and rebound hammer relevant to their testing system. Such relationships are not appropriate for all concrete types; for this reason, they must be calibrated for different mixtures [18]. To overcome this issue, destructive testing (DT) combined with non-destructive testing (NDT) is proposed to lessen cost and time-consuming approaches and increase testing quality [13]. Lawson et al. [19] investigated the relationship between the sole ultrasonic pulse velocity (a NDT) and concrete's compressive strength. Jain et al. [20] used different NDTs in combination for guessing concrete strength. Ali-Benyahia et al. [21] performed a study that examines models between DT and NDT in combination or individual (Rebound hammer

*Corresponding Author: ilkertekin@karabuk.edu.tr
(İ. Tekin Orcid: 0000-0001-7400-4790)

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and ultrasonic pulse velocity). The results of the studies showed that combining destructive and non-destructive tests to estimate the concrete strength are highly recommended and give more accurate results leading to an increase in the quality of tests [22].

In this experimental study, destructive and non-destructive methods are applied at a slab and beams to ensure these elements' suitability for design parameters. This study aims to determine bad conditions areas of a slab and beams and make a sight-seeing to the standards because of its weakness in concrete with composite cements.

2. Material and Methods

2.1. Material

The project's concrete class was C25/30 type ready mixed concrete, and the concrete was produced with CEM II/B-S 42.5N and CEM I 42.5R types of cements. CEM II type cements are already cheaper than the CEM I type cement, hence CEM II/B-S 42.5N type cement is frequently used as slab concrete in some buildings in Karabük. Moreover, as it is well known that the CEM II/B-S 42.5N type cement reduces the heat of hydration and permeability. Natural river and crushed stones were used as aggregate. The material quantities of each truck mixer transferred from the concrete plant are given in Table 1.

According to the table data, the total amount of concrete poured was approximately 130 m³. Around 296–313 kg/m³ dose binder was used in each truck mixer. The water/cement ratio used in mixes was between 0.57–0.67. The water/cement ratio was increased after the first nine truck mixers because the plasticizer was used at the rate of 1.2% in the first nine truck mixers. CEM II/B-S 42.5N type cement is produced with approximately 35% slag substitution instead of clinker. 5th floor slab is a part of the 8-storey building with a total area of 600 m² and 129 m³ concrete production. During production, concrete was cast with 15 truck mixers as given in Table 1. First 7 ready-mix concrete were poured into beams, afterwards slabs were poured. The average compressive strength from the control specimens in 150 mm cubic form belonging to the relevant part of the structure was obtained as 17 MPa for 28 days of age. According to TS EN 12390-3 [23], the lowest strength value of this value, which is the average of 12 samples, was obtained approximately 13 MPa, and the highest strength value was obtained as approximately 27 MPa taken from some of trans-mixers. Accordingly, on-site inspection is foreseen in the relevant part of the building.

Figure 1. A concrete sample of the slab before compressive strength test at 28 days

An example of samples taken on-site and below the strength limits are shown in Figure 1. Dusting behavior is also observed in the test samples' surface view after the 28-days of curing. Besides, a weak structure with the behavior generally seen in concretes with a high w/c ratio and poor gradation is clearly observed.

Table 1. Mix design of each mixer truck used in concrete production for the slabs and beams.

No	Volume (m ³)	CEM I (kg/m ³)	CEM II (kg/m ³)	w/c (%)	Plasticizer (%)
1	7	300	-	61	1.2
2	4	299	-	61	1.2
3	10	301	-	59	1.2
4	10	299	-	59	1.2
5	10	308	-	57	1.2
6	9	225	74	59	1.2
7	10	300	-	59	1.2
8	10	-	300	59	1.2
9	6.7	-	296	60	1.2
10	10	-	305	65	-
11	10	-	318	63	-
12	4	-	308	64	-
13	9	-	309	66	-
14	10	-	301	67	-
15	10	-	309	65	-

2.2. Methods

The studies planned to be carried out to determine the slab and beams concrete's strength and performance to which a group of specimen's compressive strength was below the limit value. The conditions specified in TS EN 13791 [24], BS1881-120 [25] and TS EN 12504-1 [26] standards were worked with it. To determine the slab's concrete strengths, the most suitable for this project is the alternative method according to TS EN 13791, and planning was done accordingly. Then, evaluations were made on a total of 18 core samples according to the alternative method. In this context, the SH test application planning was carried out by considering the concrete pouring places from the various points of the slab and beams, and then a total of 18 cores were taken from several points on the slab and beam.

There are three different alternatives for conformity assessment in TS EN 13791. These alternatives vary according to the amount of concrete and the use of indirect methods. One of them is using core sampling and SH tests together called mix approach. In this assessment at least 2 cores must be taken from lowest strength areas, after applied at least 15 SH measurements randomly. Afterwards, some of calculations need to be done to evaluate sufficient or insufficient of concrete according to given equation below.

f_{is} , the lowest $\geq 0.85x (f_{ck}-4)$

f_{ck} = Standard sample characteristic compressive strength

f_{is} , the lowest = the lowest of the compressive strengths in the structure

2.2.1. Concrete test hammer applications

Totally 69 points on the slab (20x20 cm area) were determined to perform SH test as shown in Figure 2. In addition, SH test points were defined at randomly 5 points from the beams' bottom and side points. Thus, a total of 74 concrete test hammer measuring points were determined. From these defined points, using SH of N-type Proceq, the data were formed with at least 10 measurements from each point on the slab and beam surfaces. The measurements showed low, medium, and high strength places for the concrete. In this context, a total of 18 cores were taken. The purpose of the application is to ensure that the concrete test hammer data can be correlated with the core data. SH test measurements were carried out on a slab and beams. The graphic given in Figure 3 was used to convert 15x15x15 cm cube equivalent compressive strength corresponding to the SH test values obtained in the field and the Proceq N-type hammer's rebound values.

Figure 2. SH application points on a slab (R: SH points from slab, Rk: SH points from beams)

Figure 3. The relationship between the equivalent cube compressive strength of the SH test obtained in concrete with different binders [27]

2.2.2. Experimental program

In the study, within the scope of regulation 9/B specified in TS EN 13791, it was found that the appropriate use of the above-mentioned alternative method on core samples, is to be primarily within 36 days of production. However, considering the results arising from the transfer of a small number of cores in this experimental program to the whole production, a total of 18 cores were taken and evaluated at the age of 78 days. As it is known, structural but local problems may occur during production due to labor and other factors. These problems often do not mean that the whole manufacture poses a risk, especially in elements such as a horizontal carrier. The solution should be produced by transferring the relevant data to the structural designer and the final decision should be accepted by him. The SH test data were obtained from 74 points on the slabs and beams, and then these data were clarified with descriptive statistical calculations. After calculating the average and standard deviation from the SH test data, the core taken from the slab from 5 different points at the age of 36 days from the weakest strength, medium strength, and high strength areas. To correlate these core data with test hammer data, additional 2 cores were taken from random points. In addition, the concrete test hammer data was taken from two different beams that create low and medium strength, and a correlation curve was created between the concrete test hammer and the core strengths. When the R-value obtained by calculating the correlation coefficients exceeded 80%, the compressive strength data of the test hammer were updated over the correlation equation. Thus, the points on the whole slab were associated with the correlation equation giving the equivalent cube strength and the slab's strength performance.

Concrete test hammer data should not be used for design purposes according to current standards and should not be considered in the assessment. However, it has been added to the report to create the slab performance. Thus, a situation plan of the slab was created in line

with the data obtained. The classification of symbol colors used in the conditioning plan is as follows:

- Red color: Areas less than 22.1 MPa ($\leq ((f_{ck}-4) \times 0.85)$)
- Yellow color: Areas between 22.1 MPa and 26 MPa ($((f_{ck}-4) \times 0.85) \leq \dots \leq (f_{ck}-4)$)
- Green color: Defined areas for 26 MPa and above ($((f_{ck}-4) \leq \dots$)

2.2.3. Information on taking and evaluating cores

After the test hammer applications, according to the correlation curve between the hammer values given in Figure 3 and the compressive strength, it was ensured that a total of 9 core samples were taken from the points with the lowest, medium, and high strengths at 36 days. Then, a total of 4 core samples of 68 days and 70 days of age were taken from the weak points of the slab. In addition, 6 cores were taken from various points of the slab again at the age of 78 days. A total of 16 core samples were taken vertically from the slab, and 2 were taken from the beams horizontally. Core samples were taken in the vertical direction in the slab as seen in Figure 4, and in the horizontal direction from the point where the shear in the beam was zero. The aggregate used to produce the concrete is with a grain size of $D_{max}: 22.4$ mm. Thus, $3 \times D_{max}$ is the condition applied as specified in the TS EN 13791 standard.

The samples were kept dry for 3 days in the laboratory at 75% relative humidity and 22 °C, as shown in Figure 5 since they were extracted with a wet method. Before performing the compressive strength test, the upper and lower surfaces were smoothed by a dry cutting machine. After smoothing the surface of the samples, the length, diameter, and weight of the samples have been taken. Then, compressive strength tests were carried out with a uniaxial of 200 tons capacity hydraulic press machine with a constant loading rate of 0.5 MPa/s. After that, the breaking time of the samples was recorded.

According to TS EN 13791, conversion coefficients with proven suitability should be taken as a basis in the conversion of test results obtained from cores with diameters starting from 50 mm up to 150 mm and having different length/diameter ratios. Besides, conversion coefficients with proven suitability for samples with sample sizes and length/diameter ratios (λ) can be included in the valid provisions where the cores are used. Under normal conditions, correction is not made in the core test results by considering the coring direction, except when required by the applicable provisions or in the project specification where the cores are used. According to the BS 1881-120 (1983), the equivalent cube strengths are calculated with the correction coefficients created using the equation formulas given below (λ : slenderness coefficient). For core samples taken horizontally according to the casting direction of the concrete:

- Core samples taken horizontally according to the casting direction of the concrete: $K_{CUBE,15 \times 15} = 2.5/(1.5 + 1/\lambda)$
- Core samples taken vertically according to the casting direction of the concrete: $K_{CUBE,15 \times 15} = 2.3/(1.5 + 1/\lambda)$
-

Figure 4. Vertical core extraction from a floor slab

Figure 5. Core samples taken from slab and beams

After converting the compressive strength values to the equivalent cube strength, the "Assessment in Cases Where Concrete Conformity is Doubtful According to Standard Tests" approach specified in regulation 9/B of TS EN 13791 was used in the conformity calculations. Accordingly, some definitions are given below:

- fis: Compressive strength test results
- fis lowest: The lowest of the compressive strengths results
- fm (n): average of compressive strength in place of n
- fck: Characteristic compressive strength in the structure
- fck cube: Characteristic compressive strength in the structure, expressed as equivalent to 150 mm cube strength
- fck, is, cylinder: Characteristic compressive strength, expressed as equivalent to 150/300 mm cylinder strength

Since the concrete class planned in the study is C25/30;

- fck, is, cube: 26 MPa fck, is, cylinder: 21 MPa

According to regulation 9 and Alternative 2 (approach B) of TS EN 13794, at least 15 SH test readings and two core results should be obtained from the weak areas. According to regulation 9, conformity assessment was made using the formula below:

- fis, the lowest $\geq 0,85x(fck-4)$

The lowest beam strengths were considered in the evaluation. Finally, after the concrete SH results were calculated and using the correlation equation according to the equivalent cube strengths, the slab's condition was established.

3. Results and Discussion

Information on concrete SH rebounds and core samples obtained within the framework of the test program are given in Table 2 and Table 3. The data in Table 2 includes the statistical analysis of the concrete test hammer data obtained from a slab and some beams of the building. The correlation equation was created using the average concrete test hammer values and the core data together and presented in Figure 6. Although at least 15 concrete test hammer measurements with 2 cores were sufficient in the test setup created according to TS EN 13791 - regulation 9/B, concrete SH measurements were made from the relevant slab and beams at a total of 75 different points from the 36-day-old slab. 7 points were determined from the areas in the lower, middle, and upper limits of the concrete test hammer values and 9 separate cores were taken from these 7 points. The reason for the large number of coring is to provide an idea about the whole slab by obtaining the correlation of the concrete test hammer values with the compressive strengths of the core samples and the equivalent cube pressure strengths. Besides, an evaluation was made with cores taken from some parts of the slab at the age of 63, 70 and 78 days. Table 3 present the cores and concrete test hammer results. The average equivalent cube compressive strengths established from Table 3 is 30.86 MPa for the slab.

Figure 6. Correlation diagram between concrete test hammer and core data at 38th day

According to the core samples' compressive strength results, the conformity analysis was conducted according to the alternative method specified in TS EN 13791. According to this method, there should be 2 cores for checking the compressive strength and 15 SH results as a minimum. In this study, according to the equivalent compressive strength test results of the core sample taken from the slab at the age of 36 days, the lowest compressive strength was obtained as 20.42 MPa and the highest 48.79 MPa. The compressive strength average value of the slab core samples was approximately 31.39 MPa. This value provides the characteristic compressive strength design limit. However, it is seen that the strength limits in some areas on the slab are below the design limits.

Considering the equivalent cube compressive strength values of core samples, it can be said that only one sample is below the design limits. Although the weak strength limits occurring in a certain area of the slab are not considered appropriate in terms of quality control evaluation, it has been predicted that the red areas will turn yellow, and the yellow areas turn green due to the time-dependent strength development behavior approaches of the concrete with slag additive. For this reason, it was considered to check the strength limits by taking another core from the weak area at the age of 63. Compressive strength test with a constant load of approximately 2.6 kN/s was carried out on the core taken from the deck (R6 point). According to the analysis results seen in Table 3, the parallel cube compressive strength of 21.52 MPa was obtained from the 63 days old core sample. Thus, according to the 63-day wet core compressive strength test result of the slab's weakest point, the strength increase was approximately 6% compared to the previous period. As a result of the experiment performed on another core taken from R6 at the age of 78 days, the equivalent cube compressive strength value was obtained as 22.48 MPa. Thus, the R6 region gave conformity by exceeding the lowest value of 22.1 MPa. Because of the 70-day-old core test taken from another weak zone, R5 area, the equivalent cube strength was obtained as 22.15 MPa, and it gave conformity in the same area. Again, in the non-destructive and non-destructive quality control study performed for 36 days, the equivalent cube compressive strength of the core sample taken at 78 days from the R2 area, which was determined as another weak flooring, was obtained at the age of 38.56 MPa, appearing in a result above the minimum value of 22.1 MPa. has been taken.

Strength values were obtained. The average beam compressive strength obtained from the core samples and equivalent cube compressive strength data were above the limits. In both approaches, the strength was above the limits, both in evaluating the core samples and according to the equivalent cube compressive strength data after the correlation of the SH test values. Since there are doubts about the suitability of evaluating slab core samples in most literature approaches, the result of the core samples of beams, according to BS1881-120 (83) standard is 30.58 MPa. Since this strength is greater than $(F_{ck}-4) \times 0.85$ ($=22.1$ MPa) according to TS EN 13791, the results obtained from the core tests have been found appropriate. Figure 6 is based on the correlation between concrete test hammer data and core results derived from the same region on the slab.

Table 2. Concrete SH rebounds and descriptive statistical calculations

Code	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
n	12	12	13	11	11	15	12	10	10	10	10	15	10	10	9
Max.	21.5	22.5	31.5	25.0	22	23	30	30	34	31	32	26	30	30	32
Min.	21.0	20.5	27.0	21.0	21	20.5	27	29.5	30	29	29	21	25	27.5	29
Avg.	21	21	30	22	22	22	29	30	32	30	30	23	28	29	30
S.Dev.	0.23	0.54	1.28	1.22	0.27	0.68	0.88	0.26	1.56	0.68	0.89	1.87	1.74	0.70	1.32
Code	R16	R17	R18	R19	R20	R21	R22	R23	R24	R25	R26	R27	R28	R29	R30
n	9	11	12	10	15	15	10	15	16	13	20	15	15	15	14
Max.	30	32	29	30	30	32	30	28	29	27	26	29	25	30	28
Min.	29	29	27	29	26	26	29	25	24	22	20	24	21	25	24
Avg.	29	30	28	29	28	29	29	27	27	24	23	26	23	28	26
S.Dev.	0.44	0.84	0.90	0.48	1.44	1.47	0.48	1.21	1.71	1.78	2.27	1.49	1.58	1.58	1.45
Code	R31	R32	R33	R34	R35	R36	R37	R38	R39	R40	R41	R42	R43	R44	R45
n	14	14	15	16	20	19	15	15	11	11	10	12	17	16	14
Max.	29	22	34	29	27	27	27	32	32	35	33	25	29	26	29
Min.	24	20	30	28	21	24	24	26	30	33	30	20	24	21	24
Avg.	26	21	31	29	23	25	25	29	31	34	31	22	26	24	26
S.Dev.	1.74	0.47	1.19	0.30	1.93	0.98	1.08	1.71	0.66	0.67	0.84	1.83	1.61	1.90	1.58
Code	R46	R47	R48	R49	R50	R51	R52	R53	R54	R55	R56	R57	R58	R59	R60
n	15	15	12	15	11	20	20	21	12	14	12	13	20	9	16
Max.	27	30	30	29	27	27	30	25	21	29	24	29	26	34	27
Min.	22	24	27	24	24	21	21	20	18	25	21	24	21	30	21
Avg.	24	27	29	26	26	24	24	22	20	27	22	27	23	31	24
S.Dev.	1.41	2.28	1.08	1.59	1.10	2.02	2.47	1.61	0.89	1.78	0.89	1.46	2.09	1.32	1.9
Code	R61	R62	R63	R64	R65	R66	R67	R68	R69	K70 _y	K71 _y	K72 _A	K73 _A	K74 _A	K75 _A
n	10	11	10	16	15	11	11	19	12	10	14	12	10	10	13
Max.	26	29	24	31	27	31	33	25	33	34	26	25	33	29	34
Min.	21	26	21	27	22	29	30	20	29	29	21	21	28	24	30
Avg.	23	28	22	29	24	30	31	23	32	31	23	22	30	27	32
S.Dev.	1.5	1.1	0.9	1.3	1.7	0.8	0.8	1.9	1.7	1.5	1.7	1.6	1.4	0.8	1.56

*S.Dev: Standard deviation, Max: Maximum value, Min: Minimum value, Avg.: Average, y: Horizontal SH test, A: Bottom SH test

Table 3. Core samples and concrete test hammer information

Location	Dia. (mm)	Height (mm)	λ	BS1881 Corr.	Ultimate load (kN)	f_{is} (N/mm ²)	BS1881 $f_{ck, is, cube}$ (N/mm ²)	Sample age	Unit weight (kg/dm ³)	
Slab	R2	74.8	106	1.42	1.04	162.4	36.98	38.56	78	2.2
	R5a	72	96	1.33	1.02	81.3	19.98	20.4	36	2.2
	R5b	74.8	103.5	1.38	1.03	94	21.4	22.15	70	2.2
	R6a	75.2	69.2	0.92	0.89	107.4	24.19	21.5	63	2.1
	R6b	74.8	105.9	1.42	1.04	94.7	21.56	22.48	78	2.3
	R15	74.8	106.5	1.42	1.04	143.5	32.67	34.1	78	2.3
	R23a	72	89	1.24	1.00	109.5	26.9	26.8	36	2.3
	R23b	72	111	1.54	1.07	96.9	23.08	25.49	36	2.3
	R36	74.8	99.8	1.33	1.02	140.8	32.06	32.78	78	2.3
	R40a	72	117	1.63	1.09	182.6	44.87	48.79	36	2.4
	R40b	72	82	1.14	0.97	142.1	34.9	33.77	36	2.3
	R55	72	125	1.74	1.11	104.4	25.65	28.4	36	2.3
	R58	74.8	104.8	1.40	1.04	128.2	29.19	30.3	78	2.2
	R59	74.8	85.6	1.14	0.97	187.2	42.62	41.3	78	2.3
	R69	72	96	1.33	1.02	143.5	35.26	36.05	36	2.3
Beam	K70	72	103	1.43	1.14	142.1	34.9	39.7	36	2.3
	K74	72	119	1.65	1.19	104.8	25.75	30.58	36	2.2

*V: Vertical, H: Horizontal, Dia.: Diameter, Corr.: Correction

Table 3 shows the results of the core tests taken at older ages from the slab's when they were in red areas. It is seen that the equivalent cube compressive strength of the cores taken from the red areas of the slab at the age of 63, 70 and 78 days is over 22.1 MPa. In addition to this, the core values taken from the other yellow and green areas of the slab increased at certain rates or remained the same. Accordingly, the same strength was obtained at 78 days in the core taken from R15, which was tested at the age of 36 days, while the compressive strength increased by 20% in R36 from 36 days to 78 days, 32.78 MPa, and 22 MPa at 36 days at the age of 78 days, 30.33 MPa strength was obtained. Thus, the strength increases in the R58 region reached approximately 40%. In addition, in the core sample taken from the region numbered R59, the compressive strength increased by about 15% according to the compressive strength at the age of 36 days. The results are compatible with the literature [28, 29].

On the other hand, some concrete SH values and one of the compressive strength values obtained from 7 core samples were obtained on the slab, below the limit value. From the result, the core test samples taken from the slabs at the age of 78 days created values higher than the lowest compressive strength limit value according to the Alternative method, which is the application of regulation 9/B of the relevant standard and provided the conformity criteria in the relevant field. Using the correlation equation obtained in Figure 6, all concrete test hammer values obtained from the field were converted into equivalent cube compressive strength (in MPa) with approximately R2= 86% accuracy. Three areas were made for the converted compressive strengths as shown in Figure 7. Thus, the color symbols are processed on the performance evaluation map in Figure 7 for the slab. In this given condition map, the local red and yellow areas are draw attention. The reason for these areas' weakness is thought to be due to application error rather than poor concrete quality. Inadequate execution, bleeding problems, excessive settlement of coarse aggregates, and the formation of microcracks resulting from this can cause a decrease in strength in slab concretes.

Figure 7. The classification of the slab strength at 38th day: Red color: Areas ≥ 22.1 MPa, yellow color: areas between $22.1 - 26$ MPa, and Green color: defined areas for 26 MPa $\leq$

Table 4. The results of the concrete test hammer data taken from the slab and converted to the equivalent cube compressive strength with the correlation equation

Code	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
R	21	21	30	22	22	22	29	30	32	30	30	23	28	29	30
A	16.5	16.5	27.5	17.0	17.0	17.0	26.0	27.5	29.0	27.5	27.5	18.0	24.5	26.0	27.5
B	19.6	19.4	33.5	20.6	20.1	20.1	31.7	33.2	37.2	34.1	34.1	22.4	30.9	31.7	34.2
Code	R16	R17	R18	R19	R20	R21	R22	R23	R24	R25	R26	R27	R28	R29	R30
R	29	30	28	29	28	29	29	27	27	27	24	23	26	23	26
A	26.0	27.5	24.5	26.0	24.5	26.0	26.0	23.0	23.0	23.0	19.0	18.0	21.9	18.0	21.9
B	32.3	33.9	30.9	32.4	30.1	32.0	32.4	27.8	28.8	23.6	21.7	26.5	22.7	29.7	26.5
Code	R31	R32	R33	R34	R35	R36	R37	R38	R39	R40	R41	R42	R43	R44	R45
R	21	31	29	23	25	25	29	31	34	21	31	22	26	24	26
A	16.5	29.0	26.0	18.0	20.7	20.7	26.0	29.0	33.5	16.5	29.0	17.0	21.9	19.0	21.9
B	26.3	19.3	35.7	31.8	22.9	26.0	25.7	31.6	35.2	41.5	36.1	20.9	27.0	23.0	26.6
Code	R46	R47	R48	R49	R50	R51	R52	R53	R54	R55	R56	R57	R58	R59	R60
R	24	27	29	26	26	24	24	22	20	27	22	27	23	31	24
A	19.0	23.0	26.0	21.9	21.6	19.0	20.0	17.0	15.0	23.0	17.0	23.0	18.0	29.0	20.0
B	24.5	29.0	31.2	27.7	26.5	23.4	24.0	20.1	18.4	28.9	20.3	28.8	22.5	36.0	23.5
Code	R61	R62	R63	R64	R65	R66	R67	R68	R69	K70	K71	K72	K73	K74	K75
R	23	28	22	29	24	30	31	23	30	31	23	22	30	25	32
A	21.0	24.5	17.0	26.0	20.0	27.5	29.0	21.0	27.5	29.0	18.0	17.0	27.5	20.7	30.0
B	21.8	30.1	20.5	31.2	24.1	33.4	35.4	22.0	33.8	35.0	21.6	21.1	33.8	25.6	36.3

*R: Average rebound values, A: SH guide's cube strength (MPa), B: SH correlated equivalent cube strength (MPa)

These results are given in Table 4 collectively. As shown in Table 4, the equivalent cube compressive strength values of the slab and beams are distributed between approximately 18.4 MPa - 41.5 MPa. According to the data obtained from this study, less than 10% of the slab's performance appears to be low. However, as explained in the first part, the strength expected to increase at least 20% after 28 days of age in concretes produced using pozzolanic binders. With this strength development, all red and yellow areas are expected to turn green by the age of 90 days. The study suggested a more qualified curing of the concretes produced with pozzolanic cement types (such as slag cement). Because water and moisture are required for pozzolanic reactions to continue the development of strength healthily, otherwise, the reaction slows down owing to the low relative humidity of the environment and the development of compressive strength cannot be at the inappropriate environment.

4. Conclusions

- Slag based concretes give their ultimate strength at least after 90 days of production; therefore, the evaluations about compressive strength values of building elements such as slabs and beams should be arranged in some standards by development of binder type.
- Compressive strengths of well-cured slabs and beams produced with slag-based concrete are obtained at least 6% between 36th day and 63rd day and 8.5% between 36th and 70th day.

Among the equivalent compressive strength values converted from the concrete SH, the compressive strength values based on the correlation obtained for the red regions were found in the area belonging to the test hammer data with the minimum value of 18.4 MPa. This area is an example of the problems mentioned above. Although the concrete test hammer values are strengthened by correlating them with the core data, the use of the obtained transformed results in building design or evaluation are not recommended according to the scientific literature. After 78'day from construction, red regions transformed into yellow state and the yellow regions transformed into green state according to the last core tests. Using the correlation equation obtained in Figure 6, the non-destructive concrete test hammer average values obtained in the field were converted into equivalent cube compressive strength with 82% reliability.

- In terms of compressive strength before 70th day of production and after the 70th day results are different from each other because the concrete is slag-based.
- Compressive strength results derived from the rebound hammer test by guidebook are too different from the obtained results. There is a quite high correlation between Rebound hammer test results and core compressive strength values. Hence, this correlation can be used as a correction factor for rebound hammer test values.
- If there is a requirement for an evaluation for a new buildings' elements such as slabs or beams that have such a wide area, rebound hammer tests can be used to check concretes' reliance on the core data.
- If an evaluation is required for a slab or beams of a newly constructed building, at first it should be determined which binder type was used in the concrete mix.

Declaration of Conflict of Interests

The authors of this paper declared that there is no conflict of interest in this research paper.

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