



Determination of surface properties of different formwork release agents on strength concrete ☆

Gökhan Durmuş ^{a,*}, Damla Nur Çelik ^a, Rüya K. Demircan ^b, Erengül Ç. Demirci ^c

^aGazi University Department of Civil Engineering, Faculty of Technology, Ankara, Turkey

^bSinop University Construction Department, Boyabat vocation School, Sinop, Turkey

^cGazi University, Institute of Science, Ankara, Turkey

ARTICLE INFO

Article history:

Available online 10 January 2023

Keywords:

Wood formwork
Formwork oil
Compressive strength
Ultrasound velocity
Carbonatization

ABSTRACT

In this study, concrete samples were poured into mold using three different formwork oils and the impact of formwork oil on concrete surface hardness and carbonatization was investigated. 60x60x10 cm³ sized wood formworks were produced by class II pine timber. Three kinds of formwork oils were used such as standard (K1), concentrate (K2) and plywood formwork oils (K3). Concrete blocks were developed by pouring the C20 strength class of concrete into formworks. Concrete surface hardness and carbonatization depths were measured by taking cores giving dimensions of $\phi 50 \times 100$ mm. The results revealed that the highest surface hardness and carbonatization values were obtained from concentrate formwork oil. The surface hardness was 10 % higher and the carbonatization was 49 % least than oil-free formworks. Copyright © 2023 Elsevier Ltd. All rights reserved.

Selection and peer-review under responsibility of the scientific committee of the 4th International Engineering Research Symposium.

1. Introduction

Formwork is a temporary structure created to provide the desired shapes and dimensions and to support the concrete until it becomes strong enough to support its own weight [1–3]. Formwork plays a significant role in the rough work. Formwork is crucial for the aesthetics of concrete surfaces in addition to these essential roles. The concrete's surface and formwork design errors are known to cause surface flaws that affect the concrete's physical and mechanical properties [4–6]. Additionally, concrete's surface can be improved to increase durability [7,8].

The surface hardness of the concrete is investigated by using ten different formworks with four primers with varying permeability under atmospheric conditions [9]. It is found that formworks that are covered with geotextile primers are affected less by atmospheric effects and concretes that are produced using formworks

with primers have better surface performances than without liners [10]. Besides, the level of carbonation of concrete is investigated on seven different formworks. Concretes poured into formworks that have primers with drainage channels have less carbonation level than scotch pine, black poplar, sheet iron, and plywood formworks. Indeed, concrete poured into SB-20 geotextile primer-covered formwork with drainage channels has the minimum and sheet iron has the maximum depth of carbonation [11].

Concrete surface hardness test methods are well known for providing advanced information and roughly indicating the quality of concrete. Especially like the type of cement, cement ratio, type of aggregate, concrete surface form, surface humidity state, carbonation, concrete age, initial hardening time, curing, and compaction, the quality of concrete is affected by a variety of factors [12,13]. Because of these factors, the concrete strength can be estimated with a 15 %–40 % margin of error [14].

Carbonation in reinforced concrete is one of the major factors of the corrosion effect in reinforcing bars [15,16]. As a result of the carbonation reaction, the amount of calcium hydroxide decreases, and thus the pH value reduces. This low pH condition accelerates the corrosion of reinforcing bars. The carbonation effect starts from the surface to the inner parts of the concrete. Therefore, the depth of carbonation should be determined on the concrete samples [13,17,18]. Permeability of concrete and micro-cracks surface

Abbreviations: Var., Variable.

☆ Selection and peer-review under responsibility of the scientific committee of the 4th International Engineering Research Symposium (INERS'22).

* Corresponding author.

E-mail addresses: gdurmus@gazi.edu.tr (G. Durmuş), damlanur.celik@gazi.edu.tr (D.N. Çelik), rkdemircan@sinop.edu.tr (R. K. Demircan), erenugm@hotmail.com (E. Ç. Demirci).

<https://doi.org/10.1016/j.matpr.2022.12.263>

2214-7853/Copyright © 2023 Elsevier Ltd. All rights reserved.

Selection and peer-review under responsibility of the scientific committee of the 4th International Engineering Research Symposium.

increase with the increment of carbonation depth on the concrete [11,18,19]. In this study, the effects of three different types of formwork oil on the surface hardness and carbonation level of the concrete samples are investigated.

2. Materials and methods

2.1. Materials

In the concrete mixture, river sand, crushed aggregates, CEM I 42,5 cement, and water are used. Formworks were prepared by using second-class pine timber. Three different oils, such as standard wooden formwork oil, concentrate formwork oil, and plywood formwork oil, were applied to the formworks. The physical properties of formwork oils are given in Table 1. The chemical, physical, and mechanical characteristics of ordinary portland cement (OPC) are given in Table 2. Furthermore, $D_{max} = 22.4$ mm and $w/c = 0.59$ were computed for the mixture in this study.

2.2. Materials

2.2.1. Prepared formwork samples

Second-class pine timber with 16 percent humidity complying with TS 1265 “coniferous sawn timbers” was used for wooden formwork [20]. Four wooden formworks were prepared to cast $60 \times 60 \times 10$ cm³ concrete (Fig. 1). Three of the oils with different properties were applied in formworks. Another formwork was used without oil as a reference. After 30 min, the formwork oil and surface dried, and the concrete was poured into the molds.

2.2.2. Prepared of concrete mixture, consolidating and cure

Concrete mixture proportions were prepared according to TS 802 standard [23]. The mix proportions are given in Table 3. The amounts of raw materials were determined for the C20 strength class.

Fresh concrete mixtures were poured into three layers, and a vibrator was applied from two points with an equal interval and

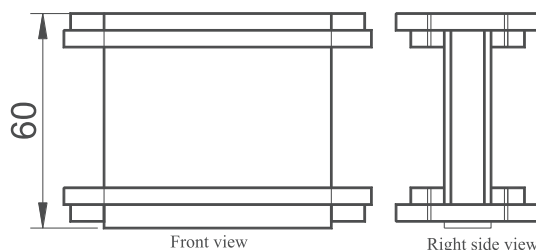


Fig. 1. Formwork appearances.

equal speed for each layer. The time of immersion was determined to be 10 s. After 24 h, the concrete blocks were removed from the formwork and cured in the water tank for 28 days at a temperature of 20 ± 2 °C.

2.2.3. Experiments of fresh concrete

Air content (TS EN 12350–7) [24], slump value (TS EN 12350–2) [25], and Ve-Be value (TS EN 12350–3) were measured in fresh concrete [26].

2.2.4. Experiments performed on core samples

The ultrasonic transmission velocity test (ASTM C805) [27], and the compressive strength (TS EN 12390–3) [28] were determined on $\varnothing 50 \times 100$ mm concrete block cores.

The measurement of carbonation depth was obtained from a total of 18 core samples (6 for each type of formwork oil). The uncarbonated surface was turned dark pink when Phenolphthalein (pH 11–12.5) solution was sprayed on the concrete. The pH value decreased to 8–9 due to carbonation and, thus the color didn't change. The carbonation depth was determined according to the Baradan [29] and Hearn [30] methods. The base indicator was prepared by adding phenolphthalein to the solution. Upon the spray of the solution including 1 % phenolphthalein and ethyl alcohol, the surface of the concrete core sample was separated into two zones since color change occurs only in the zones where the carbonation didn't occur 100 m.

Table 1

The physical properties of formwork oil.

	Standard, formwork oil, (K1)	Concentrate formwork oil, (K2)	Plywood formwork oils, (K3)
View	Yellow lucid oil	Dirty yellow lucid oil	Yellow lucid oil
Density	0,85 g/cm ³	0,85 g/cm ³	0, 80 g/cm ³
pH, [21]	7,00 – 8,00	7,00 – 8,00	7,0–7,5
Flash point, at least, ° C,	95 °C	>100 °C	110 °C
Kinematic viscosity, 40 °C N s/m ²	—	30–40 cp (20 °C)	—

Table 2

The chemical, physical, and mechanical properties of OPC 42.5.

Chemical analysis (%)	CEM I 42,5	TS EN 197–1, [22]	Mechanical Properties (MPa)			
CaO	63,35	—	Compressive strength,	Days	CEM I 42,5	TS EN 197–1, [22]
SiO ₂	20,35	—		2.	229	>10
Al ₂ O ₃	5,918	—		7.	472	—
Fe ₂ O ₃	3,06	—		28.	570	>42,5
MgO	1,89	—	Flexural strength,	7.	74	
SO ₃	2,89	< 3,50		28.	85	
K ₂ O	0,88	—				
Na ₂ O	0,58	—				
Insoluble matter	0,52	< 5,00				
Physical Properties						
Specific gravity (g/cm ³)	3,08	—				
Blaine, cm ² /g	3200	at least 2800				
Initial set (dk)	120	= >60				
Final set (sa)	3,10	—				
Volume expansion (mm)	3,0	<10				

Table 3
Material mixing properties, (1 m³).

Materials	Type	Spec. gravity. (gr/cm ³)	Weight (kg)	Volume, (dm ³)
Crushed Sand	0–5	2.69	930	347
Gravel 1	5–11	2.7	331	127
Gravel 2	12–22	2.70	596	220
Cement	CEM I 42.5	3.12	260	88
Mineral Additive	Fly ash	2.15	40	21
Chemical Additive	Plasticizer	1.18	3 (% 1.1)	–
Water	–	1.00	180	180

In the surface hardness experiment, the Schmidt hammer with 0.225 kgm impact energy was used and 100 readings were taken for each block. Surface hardness was measured according to BS 1881 and TS EN 13,791 standard on the 28, 90, and 365 days after the concrete casting [31,32].

2.2.5. Statistical evaluation

Based on the depth of carbonation and rebound numbers obtained through the core samples, a variance analysis was conducted to clarify whether there were differences among the corresponding values for different formwork oils and different times. Multiple comparison tests were conducted to determine in which groups the discrepancy existed [33]. Decisions about discrepancy among datum were based on significance levels of 0.05. On the other hand, regression analyses were conducted to determine the degree of the relation among datum and regression models; determination coefficients and scatter diagrams were plotted. Besides, 3D graphics were drawn to show the differences among groups explicitly.

3. Results and discussions

3.1. Results of fresh concrete

Table 4 shows the properties of fresh concrete. Based on the slump and ve-be test results, the concrete was classified as plastic consistency class. Furthermore, the air content of fresh concrete, slump, and ve-be values were in the margins given in the above-mentioned standards.

3.2. Surface hardness by rebound hammer

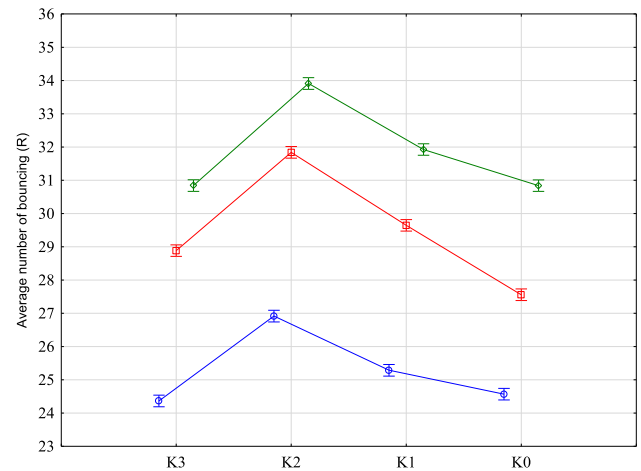
Explanatory statistics regarding the Schmidt hammer rebound numbers of the samples with their different formwork oils taken on the 28th, 90th, and 365th days as well as those of the reference sample are given in Table 5. Besides, the average rebound values are shown in Fig. 2.

A variance analysis was made to determine whether the time-related change in surface hardness values is important or not among the years according to the dates. The analysis showed that the difference among the groups is statistically important (0,05) (Table 6). In other words, it is observed that the surface hardness of concrete changes with time, and this difference is significant.

The highest and lowest rebound values, respectively, are shown in Fig. 2 for K3 formwork oil and K0 (Ref) formwork oil. Rebound values are higher for concentrated formwork oil than for dry form-

Table 4
The properties of fresh concrete.

Fresh Concrete	Concrete, (Ref)	Limit Values
Air quantity, (%)	2	Highest % 6
Slump, (cm)	15	10 < Slump < 21
Ve-Be, (sn)	8	5 < Ve-be < 31

**Fig. 2.** The Average rebound value type of formwork oil.

work. Multiple range tests were undertaken to identify the source group of the disparity in the surface hardness values Duncan (Table 7).

According to multiple range tests for the rebound numbers obtained, it is consistent with Duncan's theory.

- The rebound numbers measured are different from each other for all the different formwork types.
- The maximum rebound number value is 35,7 R for formwork oil in 365 days, and the minimum value is 27,85 R for K3 formwork oil in 28 days.
- K2 formwork oil increases in rebound numbers with increasing time.
- K2 formwork oil in 90 days is 15,5 % higher when compared to K0 formwork in 90 days, while K3 formwork oil in 28 days is 0,01 % lower than K0 formwork in 28 days.

3.3. Carbonation depth

Table 8 shows the statistics of the carbonation depth datum discovered using the phenolphthalein (C₂₀H₁₄O₄) indicator. Besides, the average depth of carbonation is shown in Fig. 3 from the statistical findings, and a picture regarding the concrete surface is shown in Fig. 4a and Fig. 4b.

According to variance analysis, there was a 0.05 significant difference between the mean carbonation depth values of concretes from molds with varying surface qualities (Table 9). In this circumstance, the carbonation depth is considered to be dependent on the mold oil type. In addition, Duncan's multiple comparison test results are given in Table 10.

According to the variance analysis, the average carbonation depths of the concrete samples with different surface properties have discrepancies at the $\alpha \leq 0,05$ significance level (Table 9). At

Table 5
Descriptive statistics for rebound numbers.

Formwork oil type	Days Var.	N	Average number of bouncing (R)	Std. Def.	According to K0, % change
K0	28	100	24,6	1,070	—
K0	90	100	30,5	0,962	—
K0	365	100	34,1	1,062	—
K1	28	100	29,9	0,969	2,9
K1	90	100	32,8	0,930	7,6
K1	365	100	35,3	0,981	3,5
K2	28	100	31,8	0,902	9,6
K2	90	100	35,2	1,006	15,5
K2	365	100	37,5	0,797	10,0
K3	28	100	28,8	0,937	−0,8
K3	90	100	32,0	0,952	4,8
K3	365	100	34,5	0,935	0,1

Table 6
The results of the variance analysis of rebound numbers.

Variance	Sum of Squares	Degree of freedom	Mean Square	F- test	Significance Level ($\alpha < 0,05$)
Formwork oil type	1878	3	626	796	0,00
Day Var.	8913	2	4456	5667	0,00
Formwork type *Day Var.	117	6	19	25	0,00

Table 7
The results of the variance analysis of rebound numbers.

Formwork oil type	Day Var.	Groups that are not the same							
		1	2	3	4	5	6	7	8
K3	28	S*							
K0	28	S*							
K1	28								
K0	90					S*			
K3	90		S*				S*		
K2	28		S*						
K1	90							S*	
K0	365			S*					
K3	365			S*					
K1	365				S*				
K2	90				S*				
K2	365								S*

Table 8
Carbonation depth values and descriptive statistics.

Formwork oil type	N	Depth of carbonation, mm	Std. Deviation	According to K0, % change value
K0 (Ref)	6	4,35	0,44	—
K1	6	2,46	0,18	56,4
K2	6	2,13	0,16	48,9
K3	6	2,24	0,17	51,4

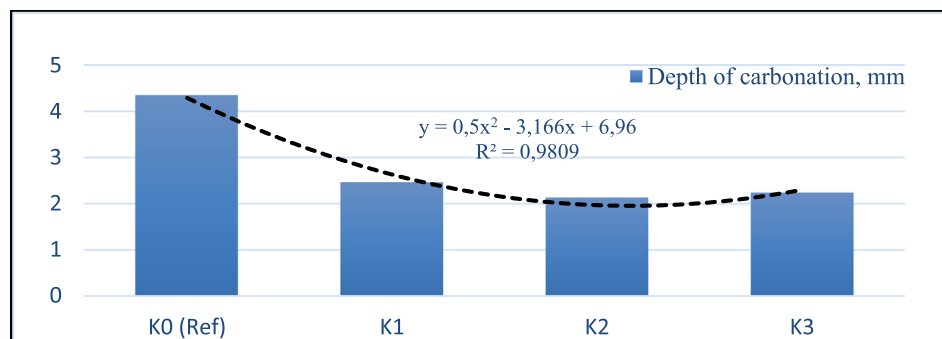


Fig. 3. Average of carbonation depth values.

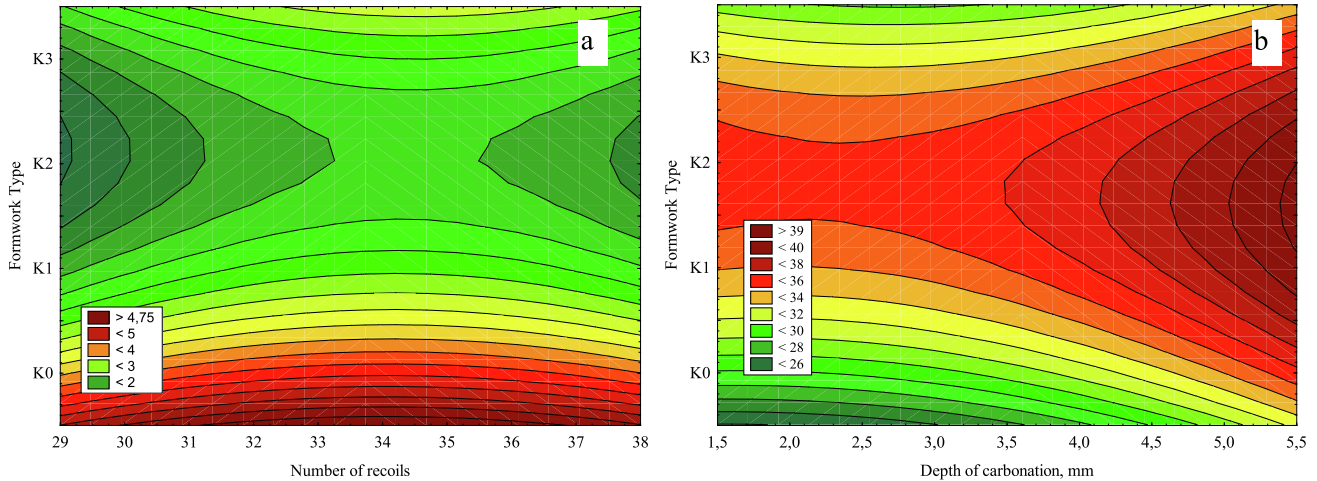


Fig. 4. The relationship between rebound values (a) and carbonation levels (b).

Table 9

The results of the variance analysis carried out type formworks oil.

Variance	Sum of Squares	Degree of freedom	Mean Square	F- test	Significance Level ($\alpha < 0,05$)
Formwork oil type	1878	3	626	92,9	0,00
Error	1,42	20	0,07		

Table 10

The results of multiple comparison test of carbonation depth values.

Formwork oil type	Day Var.	Groups that are not the same		
		1	2	3
K3	28	S*		
K0	28		S*	
K1	28			
K0	90			S*

this point, carbonation depth changes with the formwork oil. On the other hand, multiple range test results revealed similarities with Duncan's theory with respect to different formworks with different surface properties (Table 10).

- There is no difference between K3 and K1 formwork oils,
- K2 formwork oil is different than K1 and K3 formwork oils,
- The maximum carbonation depth is seen in K0 (ref) formwork

A 3D graphic shows the relationship between rebound numbers and depth of carbonation (Fig. 4a).

The relationship between the degree of carbonation and different formwork oils is shown in Fig. 4b.

4. Conclusion

According to Rebound number results.

- For each type of formwork, the measured rebound numbers are varied.
- Rebound hammer values increase with time in all formwork types.
- When comparing K2 formwork oil to K0 formwork oil in 90 days, K2 formwork oil is 15 % more expensive., whereas K3 formwork oil in 28 days is 0,01 percent lower.

According to depth of carbonation values,

- Oil-oiled standard formwork outperformed oil-free formwork by 56 %.
- It is always at its maximum in the concentrate formwork oil and at its minimum in the reference formwork.
- It increases in all formwork types with time,

The reference formwork has a minimum strength of 23.49 MPa on the 28th-day. On the 365th day, concentrate formwork reaches its peak.

In this study, all the studies on concrete samples placed in formwork using formwork oil produced superior outcomes to the control formwork. In terms of concrete surface hardness and carbonatization characteristics, concentrated formwork oil has been determined to be preferable. Based on these findings, formwork removal using concentrated oils and formwork cleaning more quickly can significantly reduce the cost of formwork and craftsmanship in concrete.

CRediT authorship contribution statement

Gökhan Durmuş: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Damla Nur Çelik:**

Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Rüya K. Demircan**: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Erengül Çalik**: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] A.S. Hanna, *Concrete formwork systems*, CRC Press, New York, USA, Marcel Dekker Incorporated, 1998.
- [2] R.L. Peurifoy, G.D. Oberlender, *Formwork for concrete structures*, 4th edition., The McGraw-Hill Companies, 2011.
- [3] Durmuş, G., M. Arslan, and S. Subaşı, "Computer Aided Design Wall Formworks For Reinforced Concrete". *3rd International Advanced Technologies Symposium*, Ankara, 2003: p. 328-341. (In Turkish).
- [4] ACI PRC-309.2R-15, Guide to Identification and Control of Visible Surface Effects of Consolidation on Formed Concrete Surfaces. *American Concrete Institute*: Farmington hills, MI, 2015.
- [5] M. Arslan, The effects of permeable formworks with sucker liners on the physical properties of concrete surfaces, *Constr. Build. Mater.* 15 (4) (2001) 149–156.
- [6] Arslan, M., The Determination of Durability Factors in Reinforced Concrete Structural Element Design: A Study on *Gazi University Journal of Science*, 9(4): 625-630. 1995. (In Turkish)
- [7] M. Arslan, The effects of drainer formworks with sucker lining on the concrete surface properties, *Turk. J. Eng. Environ. Sci.* 23 (2) (1999) 121–131.
- [8] M. Arslan, The effects of controlled-permeable formworks on the surface hardness of the concrete, *J. Faculty Eng. Architect. Gazi Univ.* 23 (4) (2008) 885–894.
- [9] O. Uluer, M. Aktaş, İ. Karaağaç, G. Durmuş, A. Khanlari, Ü. Ağbulut, D.N. Çelik, An investigation of usability of expanded perlite in heat insulation technologies, *Pamukkale Univ. J. Eng. Sci.* 24 (1) (2018) 36–42.
- [10] Arslan, M. and S. Subaşı, "The Effects of Controlled-Permeable Formworks on The Surface Hardness of The Concrete". *Journal of the Faculty of Engineering and Architecture of Gazi University*, 23(4). 2008. (In Turkish).
- [11] S. Subaşı, M. Arslan, The effects of formwork surface properties on concrete carbonation, *J. Faculty Eng. Architect. Gazi Univ.* 23 (4) (2008) 913–921, In Turkish.
- [12] ACI Committee 116, "Cement and Concrete Terminology", *ACI 116R-90*, American Concrete Institute. p. 54. 1994.
- [13] H. Hilsdorf, J. Kropp, *Performance criteria for concrete durability*, CRC Press, 1995.
- [14] S. Popovics, *Strength and related properties of concrete: a quantitative approach*, John Wiley & Sons, 1998.
- [15] K. Kurtis, W. Meyer-Ilse, P. Monteiro, Soft X-ray spectromicroscopy for in situ study of corrosion, *Corros. Sci.* 42 (8) (2000) 1327–1336.
- [16] L. Bostanci, "Effect of pore structure properties on strength properties of hybrid silica fume mortars containing randomly distributed carbon fibers", *Asian J. Civil Eng.* 22 (7) (2021) 1377–1399.
- [17] A.M. Neville, *Properties of concrete*, Vol. 4, Longman London, 1995.
- [18] Gjorv, O.E., "9th Performance Criteria For Concrete Durability". *Integrated Design and Environmental Issues in Concrete Technology*, p. 99. 2014.
- [19] Y. Ma, J. Hu, G. Ye, The pore structure and permeability of alkali activated fly ash, *Fuel* 104 (2013) 771–780.
- [20] TSI 1265, Sawn timber (Coniferous) - For building construction. *Turkish Standard Institute*, Ankara, Turkey. 2012. (In Turkish).
- [21] TSI 1262, Surface active agents - Determination of pH value of solutions or dispersions". *Turkish Standard Institute: Ankara, Turkey.* p11. 2005. (In Turkish).
- [22] TSI 197-1, Cement – Part 1: Composition, specification and conformity criteria for common cements. *Turkish Standard Institute: Design of concrete mixes.* p29. 2012. (In Turkish).
- [23] TSI 802, Design of concrete mixes., *Turkish Standard Institute: Ankara, Turkey.* p43. 2016.
- [24] TSI 12350-7, Testing fresh concrete - Part 7: Air content - Pressure Methods., *Turkish Standard Institute: Ankara, Turkey.* p. 28. 2019. (In Turkish).
- [25] TSI EN 12350-2, Testing fresh concrete - Part 2: Slump test., *Turkish Standard Institute: Ankara, Turkey.* p.11. 2019. (In Turkish).
- [26] TSI EN 12350-3, *Testing fresh concrete - Part 3: Vebe test.* *Turkish Standard Institute: Ankara, Turkey.* p.12. 2019. (In Turkish).
- [27] ASTM C805/C805M-18, Standard Test Method for Rebound Number of Hardened Concrete. *American Society For Testing And Materials.* p.4. 2019.
- [28] TSI EN 12390-3, Testing hardened concrete - Part 3: Compressive strength of test specimens. 2021, *Turkish Standard Institute: Ankara, Turkey.* p.23. 2021. (In Turkish).
- [29] Baradan, B. and S. Aydın, "Durability of Concrete (Durability, Permanence)". *Concrete 2013 Ready Mixed Concrete Congress*, p.265-288. 2013. (In Turkish).
- [30] N. Hearn, R.D. Hooton, R.H. Mills, Pore structure and permeability, in *significance of tests and properties of concrete and concrete-making materials*, ASTM Int. (1994).
- [31] BS 1881-124:2015+A1, Testing Concrete Methods for analysis of hardened concrete. *British Standards Institution (BSI).* p. 46. 2021.
- [32] TSI EN 13791, Assessment of in-situ compressive strength in structures and precast concrete components. *Turkish Standard Institute: Ankara, Turkey.* p. 44. 2019.
- [33] G. Durmuş, Investigation of penetration of water values of different concrete types, *J. Polytech.* 11 (4) (2008) 379–383.