Recent Trends in Civil Engineering and Built Environment Vol. 2 No. 1 (2021) 190–198

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Effect of Concrete Grade On Carbonation Intrusion: A Systematic Review

Nur Farah Wahidah Mohamed Ariff[1], Abdullah Faisal Alshalif[1], Mohd Irwan Juki[2]*

[1]Department Of Civil Engineering, Faculty Of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, MALAYSIA

[2]Jamilus Research Centre, Faculty Of Civil Engineering and Built Environment
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rtcebe.2021.02.01.021
Received 30 January 2021; Accepted 28 April 2021; Available online 30 June 2021

Abstract: Carbonation is one of the many important factors that affect the service life in the construction of concrete structures. The carbonation affect reinforced concrete by loss of steel passivity, that in turn results to corrosion along with spalling and cracking of concrete, but it is more durable in plain concrete since it makes the concrete completely denser, increases sulphate and alkali aggregate resistance and decrease the porosity. Suitable test procedures for the measurement of porosity and compressive strength chosen from a review of the available techniques that often been used by researchers. The outcomes of this research demonstrate the effect of the concrete grade on the intrusion of carbonation, which can lead to increases the compressive strength and reduce the porosity of concrete.

Keywords: Carbonation, Concrete Grade, Compressive Strength

1. Introduction

In present era, one of the most widely used construction materials is concrete. For its behavior, strength in concrete as a secure, strong, and simple object. Besides that, it is reasonable, low cost, and it is instantly mixed. Also, it can be designed to ensure reliable and high-quality rapid-track construction. Water to cement ratio (w/c) plays a crucial role, affecting various attributes, such as strength, workability and durability of the concrete [1].

According to Ingh et al. (2009) [2] the construction of concrete structures, carbonation is one of the important factors that can affect their lifespan. Concrete carbonation was generally defined as chemical reaction involving atmospheric carbon dioxide concentrations and the substances of cement hydration,

*Corresponding author: irwan@uthm.edu.my

especially in line with the reaction [3]. This phenomenon may have an impact on the serviceability of the structure. The carbonation effect due to carbonation in reinforced concrete is the loss of steel passivity, that in turn results to corrosion along with spalling and cracking of concrete, but it is more durable in plain concrete since it makes the concrete completely denser, increases sulphate and alkali aggregate resistance and decrease the porosity [4].

Due to carbonation of the concrete, the grade of the concrete was affected. The increase in the rate of carbonation due to the increased in the water-cement ratio has been described as a factor that affects the decrease in concrete porosity and permeability [5,6]. Therefore as result of these changes, the rate of carbonation varies for specific concrete and influences the quality of concrete. The carbonation rate is based on the concrete's porosity and water contents. Carbon dioxide diffusivity depends on the composition of the hardened concrete pore and the level of exposure. The concrete pore structure depends on the form and substance of the binder, the ratio of the water to binding medium and the degree of hydration [2]. Pore structure is one of the key factors influencing durability. As a result, the rate of carbonation intrusion varies for the different types of concrete, the concrete grade and the conditions to which the concrete is exposed.

This research aims mainly to improve understanding on the of carbonation intrusion effect on concrete grade. The objective of the study is to analyse the effect of concrete grade on carbonation intrusion which can lead to increases the compressive and reduce the porosity of concrete and to intepret the factor of carbonation intrusion that effect the concrete grade [1]. The effect of carbonation intrusion, which influence the rise in compressive strength and lowering the porosity of the concrete. Suitable test procedures for the measurement of porosity and compressive strength chosen from a review of the available techniques that often been used by researchers [7,8,9]. The rate of carbonation can be a major impact on the decrease in the permeability and porosity of concrete also influences the concrete quality [10]. Thus, this studied mainly reviews the effect of concrete grade on carbonation intrusion.

2. Methodology

A flow chart used to illustrate the method in a systematic review and appropriate protocol as shown in Figure 1. The systematic process was conducted in two publishers namely Scopus and Science Direct. Four steps of limitiation used to get the right articals and informations. Step one, search in both databased using keywords. Sept two, limitation by year, which used the period between 2010-2020. Step three, select the related articals by reading title and abstract. Step four, read the full articles then select case studies based on the validity of the study data and clear contribution.

Based on the steps on the previous paragraph three articals were used as case studies. The data and the results of the three articals were analysed and discussed systimaticaly as shown in Figure 2.

2.1 Case study

The selected case study for this reviewed in reliance of experimental work that have been conducted from other researchers [11]. The data obtained for compressive strength and porosity from 3 different experiment had been analyzed. Further discussion was made on the comparison of the compressive strength and porosity on carbonated concrete from result obtained in the previous article. Based on previous research, the selected carbon dioxide (CO_2) concentration percentage were 5 % and 10 %, while the water to cement ratio for different grade of concrete were various from 0.3 until 0.7. The previous researches were used compressive strength test on concrete cubes which is carried out using a compressive strength measuring machine to assess the load-bearing capacity of the specimens. The porosity of concrete determine by mercury intrusion porosymetry and pycnometry method.

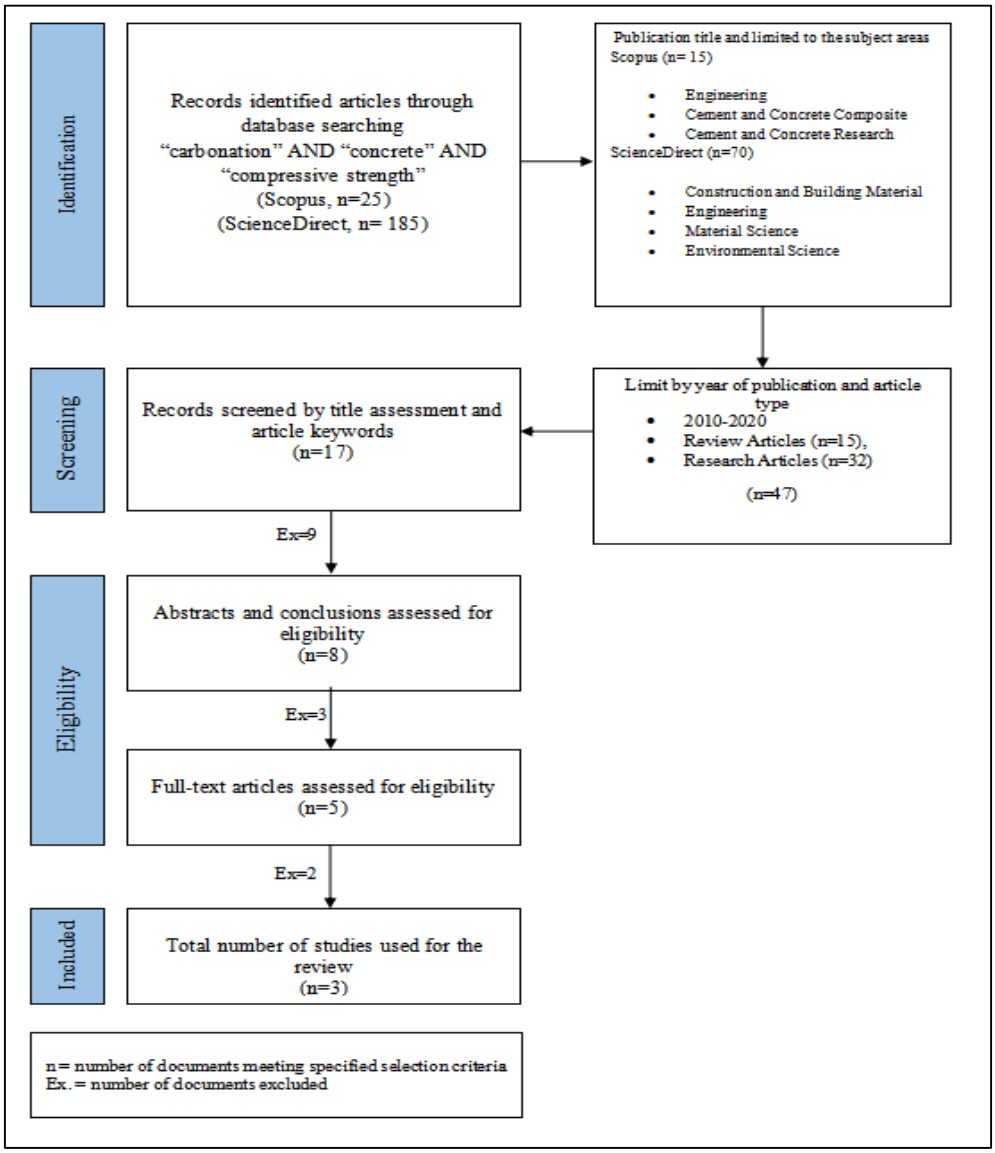

Figure 1: Steps of the review protocol.

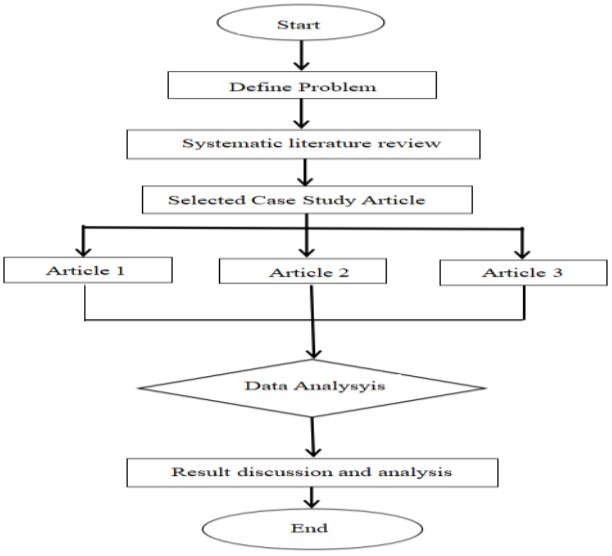

Figure 2: Flow Chart of the study

3. Results and Discussion

The experimental research is being performed by other researchers. The details collected for compressive strength was evaluated and further discussion was held. The effect was the factor determining the strength of the concrete which relate to concrete grades, such as the percentages of carbon dioxide concentration used and the ratio of water to cement for different grades of concrete.

3.1 Analyzation of compressive strength and of carbonated concrete cube

Experimental work that was carried out by [8] stated that, the effect of carbonation on the engineering properties of concrete. The effect of carbonation on three separate concrete grades, each of which has been cured for 28, 56, 90 and 120 days. Based on Table 1, its clearly showed in both carbonated and non-carbonated specimens, the compressive strength. It is obvious from this table that carbonation contributes to a rise in compressive strength. In the case of low strength concrete, the results show that strength enhancement is more significant. Compared to the non-carbonanated concrete, the compressive strength of the carbonated concretes has increased.

Table 1: Compressive strength of different grades of non-carbonated and carbonated concrete [8].

Curing (days)	Compressive Strength, MPa					
	T = 0 (Non- carbonated concrete)			T = 150 (Carbonated concrete)		
	C1	C2	C3	C1	C2	C3
28	31.76	42.81	51.20	41.79	54.19	64.00
56	38.06	46.14	53.82	49.43	56.96	65.63
90	39.44	46.25	54.13	51.22	56.40	66.01
120	40.12	47.82	56.48	50.15	57.61	68.88

The compressive strength of non carbonated concrete at 28 days for C1, C2 and C3 were 31.76 MPa, 42.81 MPa and 51.20 MPa with w/c ratio of 0.55. 0.45 and 0.40 respectively. The compressive strength of C1 was lower than C2 and C3 by 34.8 % and 61.2 % respectively. On the other hand, the compressive strength of carbonated concrete at the same period for C1, C2 and C3 were 41.79 MPa, 54.19 MPa and 64.00 MPa respectively. The difference in percentage between C1 and other C2 and C3 were 29.67 % and 53.14. The results demonstrated that, the compressives strength of non carbonatied concrete were lower than carbonated concrete. The increament of compressvie strength for carbonated concrete occurred due to the reaction between CO_2 and H_2O with the avialabe Ca cement resulting formation of calcium carbonatied ($CaCO_3$) on concrete pores, which in role increase compressive strength of the concrete [15].

The evaluation of the experimental work by [7] was checked the influence of water to cement ratio on CO_2 uptake capacity of belite-rich cement upon exposure to carbonation curing by preparing two type of cement which is ordinary Portland cement (Type 1) and belite-rich Portland cement (Type 4).

Table 2: Compressive strength of OPC mortar with normally cured and carbonation cured and different W/C

Curing (days)	Compressive Strength, MPa (OPC)									
	(Non- carbonated concrete mortar)					(Carbonated concrete mortar)				
	0.3	0.4	0.5	0.6	0.7	0.3	0.4	0.5	0.6	0.7
3	62	44	23	16	13	67	55	35	30	21
7	77	69	43	29	25	74	73	65	54	40

28	87	85	60	44	39	90	83	84	75	51

Table 3: Compressive strength of belite-rich cemen (BRC) mortar with normally cured and carbonation cured and different W/C

Curing (days)	Compressive Strength, MPa (BRC)									
	(Non- carbonated concrete mortar)					(Carbonated concrete mortar)				
	0.3	**0.4**	**0.5**	**0.6**	**0.7**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**
3	32	15	10	8	4	42	28	25	11	12
7	53	24	14	10	7	69	67	68	49	40
28	93	67	44	31	18	102	125	95	68	46

Table 2 and Table 3 demonstrates the compressive strength of mortar specimens with two types of cement namely OPC and BRC with 0.3, 0.4, 0.5, 0.6 and 0.7 of w/c and different curing conditions, normally cured and carbonation cured. In general, the compressive strength results were affected by the following factors type of cement, w/c and type of curing. The compressive strength of mortar specimens used OPC were higher than the specimens used BRC with carbonated and non carbonated curing conditions. In addition, the higher compressive strength occurred at speceimns with low w/c of both types of concrete mortar. However, the carbonated curing conditions caused an increament in compressive streght concrete mortar specimens compared to non-carbonated curing in all levels of w/c respectively. This finding in line with the previous study by [8] as presented in Table 1. Carbonation curing resulted improved compressive strength along with water to cement ratio for all cement form and both curing ages.

The study by [10] was evaluated an experimental investigation the effect of accelerated carbonation to concrete properties with varying presence of water content, as can be seen in Table 4. The increase of the duration of exposure curing in the chamber for the samples resulted an increament of the carbonation, which in role improve the mechanical properties of concrete, such as compressive strength and flexural strength [10][13]. The previous discution was confirmed the strong relation between mechanical properties of the concrete and type of cement used, curing conditons, w/c and period of curing [14,15,18].

Table 4: Compressive strength of carbonated concrete

W/C	Compressive Strength, MPa									
	Accelerated Carbonated Chamber								Water Curing	
	7	**28**	**60**	**120**	**180**	**240**	**300**	**365**	**7**	**28**
0.35	33	34	36	37	38	39	40	41	19	33
0.5	23	24	27	30	31	32	33	35	16	21
0.65	19	20	22	24	25	27	28	31	14	16

3.2 Analyzation of porosity of carbonated concrete cube

According to Das et al. (2012) [8] the effect of carbonation on the porosity of non-carbonated and carbonated specimens can be seen in Table 5. It can be found that the porosity of both carbonated and

non-carbonated concrete decreased with the increase of curing time. Moreover, the percentage of porosity in the carbonated specimens lower than the non-carbonated speciemns. The decrement percentage was occurred of the carbonated concrete porosity was due to the formation of $CaCO_3$ by carbonation process along carbonated curing [15].

Table 5: Porosity of different grades of non-carbonated and carbonated concrete

Curing (day)	Porosity in (%)					
	(Non- carbonated concrete)			(Carbonated concrete)		
	C1	C2	C3	C1	C2	C3
28	22.5	20	17.5	21	18	15
56	21	16	14.5	20	13.5	12.5
90	14.5	18.5	16	14	15.5	13
120	12.5	12.5	11.5	11.5	10.5	9.5

It can be determined on experiment evaluated by Siddique et al. (2020) [7] presents in Table 6 that the total porosity of BRC belite-rich cement paste is decreased by carbonated curing, except for BRC-0.3 and BRC- 0.5 since they are inconsistent. The major influencing factors in the amount of extruded mercury during the extrusion process were the carbonation curing and w/c, whereas the increase of w/c was resulted an increment of porosity (%) due to the chemical reaction of water and concrete materials also the evaporated water leaves pores in the concrete specimens.

Table 6: Porosity of mortar specimens with BRC after 28 days of curing

Mix no.	w/c	Porosity %	
		Normal curing	Carbonation curing
1	0.3	24.56	25.58
2	0.4	21.90	20.90
3	0.5	31.82	44.72
4	0.6	34.51	27.98
5	0.7	68.28	41.92

According to Hussain et al. (2016) [9] Table 7 shown variation of the volume of porous voids over time due to the accelerated carbonat in the concrete. The carbonation need time to take a place in concrete pores therefore the increase of curing time in accelerated carbonate chamber caused decreament of volume voids [18].

Table 7: Variation of volume of permeable voids of accelerated carbonated concrete with time

W/C	volume of permeable voids %									
	Accelerated Carbonated Chamber								Water Curing	
Curing (days)	7	28	60	120	180	240	300	365	7	28
0.35	2.0	1.9	1.6	1.5	1.4	1.3	1.2	1.0	3.7	2.5
0.5	2.2	2.3	2.1	2.0	1.8	1.7	1.5	1.3	4.0	2.9
0.65	2.6	2.5	2.4	2.1	2.0	1.7	1.6	1.5	4.5	3.0

The w/c play an important role in decrease the volume of void in concrete, when the w/c decrease the volume of voids decrease. Consequently, the lower percentage of the volume of permeable voids occured when 0.35 of w/c, while there is no big difference in the volume of porous mixture voids with w/c were 0.50 and 0.65. In summary, due to carbonation intrusion, all specimens decreased in porosity, with an improvement in the number of days of exposure. In addition, when the carbonation time increases, the porosity of concrete decreases. It makes it less permeable to the concrete and allows surface hardening [18].

3.3 Comparison of compressive strength and porosity on carbonated concrete

The comparison was done by compared the compressive strength on same amount of carbonation concentration in percentage and same duration of carbonation curing at 28 days. Table 8 and Table 9 shows the compressive strength of concrete at 28 days with carbonation concentration in each article.

Table 8: Comparison of compressive strength at 28 days with 0.4 of w/c

W/C	Das et al., (2012) [8]		Siddique et al., (2020) [7]	
	Carbonated (10%)	Non-carbonated	Carbonated (10%)	Non-carbonated
0.4	64.00 (MPa)	51.20 (MPa)	125 (MPa)	67 (MPa)

Table 9: Comparison of compressive strength at 28 days with 0.5 of w/c

W/C	Hussain et al., (2016) [9]		Siddique et al., (2020) [7]	
	Carbonated (5%)	Non-carbonated	Carbonated (10%)	Non-carbonated
0.5	24 (MPa)	20 (MPa)	95 (MPa)	44 (MPa)

From Table 8 and Table 9 its clearly showed the comparison of compressive strength of carbonated concrete with the different level of w/c . The results shows that, the compressive strength of carbonated concrete was higher than non-carbonated concrete. However, compressive strength increase at low w/c compared to higher w/c. The study by Hussain et al. (2016) [9] stated that, the lowest compressive strength was 20 MPa for non-carbonated concrete compared to other results, however the compressive strength increased slightly at the same study to 24 MPa for carbonated concrete. Result obtained by Siddique et al., (2020)[7], the compressive strength of water to cement ratio of 0.5 for non carbonated concrete is 44 MPa compare to carbonated concrete with the 95 (MPa) of compressive strength. While for water to cement ratio of 0.4, the compressive strength were 125 MPa and 67 MPa for carbonated

concrete and non-carbonated concrete respectively. This finding, can clearly highlight the affect of carbonation and w/c to compressive strength of concrete.

3.4 Effect of carbonation intrusion on concrete grade

Carbonation leads to a significant reduction in porosity of concrete, its makes the concrete more durable because of the decreases porosity which make the concrete more dense. Hussain et al., (2016) have stated that if the carbonation duration increases, the porosity of concrete decreases [9]. It makes it less permeable to the concrete and offers surface hardening. The mechanical properties of the concrete, such as its compression and flexural strength, have improved greatly due to the reduction in porosity. But the developments in these properties have decreased as the water binder ratio increased [16]. To ensure the result are related a further review had been done regarding to the concentration of carbonation and type of cement used. As the result, the carbonation has been increased the compressive strength of concrete and the reducing the porosity of the concrete. Finally, from the article reviewed it can be concluded that w/c the play the important part influenced the rate of carbonation of the concrete.

4. Conclusion

The result of compressive strength of carbonated concrete from past research been analysed from previous studies, where the compressive strength of concrete with carbonation intrusion is increase with increasing of carbon dioxide exposure duration, higher carbon dioxide concentration and reduction of water to cement ratio. The effect of carbonation on compressive strength can be decided that carbon dioxide plays a vital part in strength of concrete resulting reduction of concrete porosity and increament of compressive strength. The increase in compressive strength due to carbonation intrusion cause a change in concrete grade because concrete grades are determined by the strength and composition of the concrete, and after 28 days of initial construction, the minimum strength the concrete should have. In addition, the lower of w/c of the concrete the higher the compressive strength. Overall, the effect of carbonation intrusion in concrete is good due to its strength gained although the compressive strength of carbonated concrete are higher then normal concrete.

Acknowledgement

This research was made possible by funding from research provided by the Ministry of Higher Education, Malaysia. The authors would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] S. Zhang, X. Dong, H. Zhang and M.Deng, “Reseach on Deterioration mechanism of Concrete Material in Actual Structure”, 2014, Advance in Material Science and Engineering.

[2] S. Ingh, D. Bhunia, N. Sudhir and S. Chandra “Effect of carbonation on the properties of concrete”, 2009, 1-5.

[3] R. Tepfers, “Concrete technology porosity is decisive”, 2012, Chalmers University of Technology, 571-575

[4] S. Hussain, D. Bhunia and S. B. Singh, “Comparative study of accelerated carbonation of plain cement and fly-ash concrete”, 2017, *Journal of Building Engineering*, *10*, 26-31.

[5] K. Kovler and N. “Roussel Properties of fresh and hardened concrete”, (2011), Cement and Concrete Research41, 775–792.

[6] S. B. Singh, P. Munjal and N. Thammishetti, “Role of water/cement ratio on strength development of cement mortar”, 2015, Journal of Building Engineering, 4, 94-100.

[7] S. Siddique, A. Naqi and J. G. Jang, "Influence of water to cement ratio on CO_2 uptake capacity of belite-rich cement upon exposure to carbonation curing", 2020, *Cement and Concrete Composites, 111*, 103616.

[8] B. B. Das, S. K. Rout, D. N. Singh and S. P. Pandey, "Some studies on the effect of carbonation on the engineering properties of concrete", 2012, *Indian Concr J, 86*(3), 7-12.

[9] S.Hussain., D. Bhunia., and S. B. Singh., "An Experimental Investigation of Accelerated Carbonation on Properties of Concrete", 2016, Engineering Journal, Volume 20 Issue 2

[10] S. P.Singh, and N. Singh, "Reviewing the carbonation resistance of concrete". 2016, Journal of Materials and Engineering Structures «JMES», 3(2), 35-57.

[11] K. P. Mehta, J. M. Paulo, Monteiro, Concrete- Microstructure, Properties and Materials, 2001, University of California Berkeley

[12] B. A. Gaikwad, B. C. Rajput, "Effect of Carbonation on High Strength Concrete- Carbonation Effect on Durability of Concrete", 2017, International Journal of Engineering Research & Technology, Retrieved from http://www.ijert.org

[13] E. O. Gjorv, "Review Article - Civil Engineering, Durability of Concrete Structures", 2011, Arab Journal Science Engineering, 151-172.

[14] Y. Y. Kim, K. Lee, M., J. W. Bang, and S. J. Kwon, "Effect of W/C ratio on durability and porosity in cement mortar with constant cement amount", 2014, Advances in Materials Science and Engineering.

[15] J.H.M. Visser., "Influence of the carbon dioxide concentration on the resistance to carbonation of concrete"2014, Construction and Building Materials 67, 8–13.

[16] P. D. Bentz and C. P. Aïtcin "The Hidden Meaning of Water-to-Cement Ratio", 2008, Concrete International, National Institute of Standards and Technology.

[17] P.Patil, "Experimental Study of Fresh and Harden Properties of Concrete Infused with Carbon Dioxide", (2020), Advances in Civil Engineering and Infrastructural Development, pp 645-653.