A Study on the Flexual Strength and Quality of Free-Form Concrete Panels Using Latex

Jihye Kim [1], Byoungsik Gil [1], Hyeongun Lee [1], Hyekwon Kim [1] and Donghoon Lee [1] +
[1] Department of Architectural engineering, Hanbat National University, Republic of Korea
+ *donghoon@hanbat.ac.kr*

Article Info
Page Number: 571 – 580
Publication Issue:
Vol. 71 No. 3 (2022)

Abstract. Recently, free form architecture has become an index for national competitiveness, and there has been a growing proportion of its design. Free form architecture having curved shapes require higher flexural strength than normal concrete. LMC that uses SBR latex suppresses cracking, improves adhesive force, and enhances flexural strength and tensile strength. Therefore, a common method for improving panel quality is to use LMC mixed with SBR latex in concrete. In this study, strength, absorption rate and fluidity tests were conducted with five mixing ratios considering the moisture contained within latex to find the optimal SBR latex mixing ratio. The optimal SBR latex mixing rate found through each experiment was 9%, and panels were produced using this. Afterwards, margin of error was verified through scans. Results of the verification showed that when adding SBR latex, flexural strength and quality of free form panels produced using normal concrete improved. By increasing the mixing rate of SBR latex to more than 9% in the future, it is predicted that higher flexural strength and compressive strength can be obtained. Such additional research is expected to be actively utilized in free form panel production technologies using SBR latex.

Keywords: Free form concrete panel, SBR latex, Flexural strength

Article History
Article Received: *12 January 2022*
Revised: *25 February 2022*
Accepted: *20 April 2022*
Publication: *09 June 2022*

---

1. Introduction

1.1. Background and Purpose of Research

Since the industrial revolution of the 1980s, development of computer technologies, materials and equipment led to the improvement in design and construction technologies (Schipper, H.R., Janssen, B., 2011). Such technological development has resulted in increased interest in configuring free form architecture in the construction industry, and studies are being conducted on methods for building free form architecture (Lee, 2011; Lee, 2015). Free form architecture is architecture having slants, narrowing areas, twists or other free shapes in which all or parts of the building break away from the conventional rectangular shape (Kim, 2009). As free form architecture has curves and not just straight lines, it is different from typical architecture. Because the curves of free form architecture have different curvatures at different locations, the exterior cannot be produced with a single mold. Therefore, cutting-edge technologies like panelizing are needed to create the exterior of free form curves, but it is currently insufficient (Ryu, 2013; Oh, 2020).

This leads to insufficient design and construction management experience, making it difficult to expect profitability compared to the demand for free form architecture. In addition, unexpected problems after completion are also being highlighted (Lee, 2014). The problems are as follows. First, the shapes of free form panels are diverse, so the differential of curves grows. This raises construction costs and can result in unexpected risks. Also, the lack of expertise of technicians makes it difficult to maintain and repair free form architecture, thus resulting in the problem of increased project expenses such as LCC (life cycle cost). Secondly, as free form panels are made using concrete, extensive time and cost is needed for reproduction and reconstruction, etc. of panels due to quality issues such as bending, cracks and contraction, gaps, etc. once the building is completed. In particular, deformation resulting from bending, which can be viewed as the most vulnerable part of free form panel design, can have huge impact on the quality of the architecture. In order solve this, quality improvement of free form panel production is necessary (Kim, 2019). There is a study that claims that by mixing latex in concrete, crack suppression, abrasion-resistance, and durability can be improved (Lee, 2017).

Therefore, this study intends to find the mixing proportion that can improve quality issues of free form concrete panels (FCP) and that can enhance the flexural strength of panels by mixing in latex. Afterwards, the deduced mixing proportion will be applied to analyze the form of the produced panels.

1.2. Scope and Method of Research

Fixing free from panels on existing frames can cause the curve part to snap or cause cracks or weaken. In addition, it is difficult to use stiffeners such as reinforced concrete due to the curves of free form panels. Because of this, SBR latex is used in this study to provide resistance to weakened flexural and tensile strength. LMC (Latex Modified Concrete) is concrete that mixes latex at a certain ratio in general concrete. This causes fluidity to increase, thus raising flexural strength and tensile strength, thereby having improved adhesiveness between panels, as well as crack suppression effects. Also, latex fills the fine gaps inside concrete giving it higher permeation resistance compared to normal concrete, and it is suitable as a material for free form concrete panels (Yoo, 2006). Therefore, the purpose of this study is to produce concrete using SBR latex due to the features of panels needing high flexural strength, while reviewing the fluidity, flexural strength, and compressive strength to improve flexural strength, which is the problem of existing concrete. This study was carried out with the method shown in Figure 1.

First, the sample was examined for its properties to select SBR latex mixing quantity and W/C, and then performance tests on flexural strength, compressive strength, absorption rate, and fluidity were conducted according to changes of the SBR latex mixing ratio levels. Using the performance test results, the optimal SBR latex mixing rate for configuring free form concrete panel shapes was selected to produce the panel. At this time, manual multi-point press was used to set the displacement to produce the mold using silicon, and then concrete was placed and cured. After being removed from the mold, the produced free form panel was scanned with a 3D scanner and a quality inspection program (VXInspect) was used to compare the design shape and scan data to find the error rate. Using such results, it is reviewed on whether SBR latex is appropriate as the admixture.

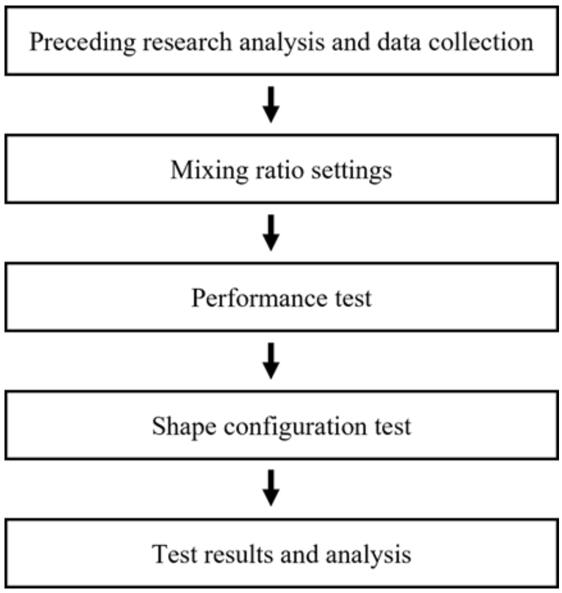

Fig. 1: The Flow of the Research

2. Literature Review

Many construction errors occur currently when producing free form concrete panels. In particular, cracks are deeply related with the tensile strength and flexural strength of free form panels, and various studies are currently underway to resolve this issue.

Oh Yeong Geun(2020) and two others used a mixed mortar instead of concrete to express a smooth shape while reducing cracks and gaps that occur when producing free form panels, and used fly ash, fine aggregate, and PVA fibers as the mixed mortar panel production material. Afterwards, the mixed mortar panel thickness was measured to perform research to find the error rate and this study claimed that error rate was more greatly affected according to the method for curing panels compared to the features of the used materials and the chemical reaction between materials, while presenting basic research methods for improving free form panel production technologies.

Choi Hoon gook and five others conducted experiments on reviewing the flexural strength features of panels per replacement ratio as a study for producing extrusion molding concrete panels by substituting fine silica, which is used as the raw material of silicate in past production, with stone dust sludge. Regarding flexural strength, which is treated as being the most important for extrusion molding concrete panels, when considering KS F 4735, it was found that the substitution rate for fine silica with stone dust sludge can reach up to 50%, while presenting research methods for substituting the raw materials of concrete. However, verification is needed to apply in free form panels (Choi, 2006).

Bae Baek il and two others conducted an experimental study on the shearing strength of steel fiber reinforced super high strength concrete not reinforced with shearing bars in order to conduct experimental verification on the safety of steel fiber reinforced super high strength concrete. The steel fiber reinforced of about 10% had increased compressive strength, and when 2% steel fiber was mixed, flexural and tensile strength doubled. The sheering performance of beams mixed with fibers was higher than general rebar concrete, and it was suggested that tensile effect from steel fiber was effective also for super high strength concrete (Bae, 2017).

Yoon Kyeong ku and three others researched the mechanical features of LMC according to the mixing rate of latex through a series of experiments. Slump, compressive strength, and flexural strength were set as the test items, and results showed that in the case of flexural strength, it was proportional with the latex mixing rate. However, it was also pointed out that when mixing rate was over 10%, the flexural strength changed little (Yoon, 2000).

F.A. Shaker and two others conducted research with the goal of examining and evaluating the main durability of Styrene-Butadiene Latex Modified Concrete (LMC). Problems with the durability and quality of existing concrete were presented and absorption test, abrasion-resistance and corrosion test, and sulphate-resistance test were conducted. Results of each experiment confirmed improvements of LMC properties compared to existing concrete (F.A. Shaker, 1997).

Choi So-young and four others compared the durability of concrete according to latex content with the latex mixing ratio. This showed that the higher the latex content, the more flexural strength and adhesive strength increased. But as latex content was not applied on free form concrete, it is necessary to check whether the increased flexural strength manifested as much as the strength required by free form concrete (Choi, 2013).

3. Body

3.1. LMC Performance Test

Table 1 shows the mixing information of this study. SBR (Styrene-Butadiene Rubber) latex mixing rate was divided into 0, 3, 6, 9, 12% as cement mixing polymer dispersion in water/cement ratio (W/C) of 45% for testing. At this time, it is calculated as the solid mass proportion (P/C) contained by the SBR latex for cement, and calculation of the unit quantity (W) in this experiment's water/cement ratio (W/C) is found by adding the quantity of moisture in the SBR latex and the applied water (w).

Table 1. Mixing information

P/C	W/C(%)	Unit mass			
		Water(g)	Latex(g)	Cement(g)	Slag(g)
0%	45	1260	0	2800	5600
3%	45	1176	168	2800	5600
6%	45	1092	336	2800	5600
9%	45	1008	504	2800	5600

The main stress target of free form concrete panel is tensile stress. This study thus conducted testing focusing on enhancing flexural strength. Compressive strength and flexural strength were measured on the 3rd, 7th, and 28th day, and the specimen was cured under water. Afterwards, curing at constant temperature and constant humidity (temperature 20±2℃, humidity 60±5%) was performed to measure the absorption rate.

Results of testing for each mixture are as shown in Figure 2, and the contents are as follows. Results of flexural strength tests on the third day showed that when mixing SBR latex at 3%, it had low levels compared to plain, but exhibited similar numbers on the 28th day. Measurements on the seventh day showed that when mixing SBR latex at 6%, it had high levels compared to plain, but exhibited similar numbers on the 28th day. In particular, measurements of flexural strength on the 28th day showed that when mixing SBR latex at 9%, it increased by 148% compared to plain, thus having the highest value as verified in (a). In the case of compressive strength, when mixing SBR latex as shown in (b), it exhibits generally low levels, but the value increases when mixing rate becomes higher. The highest compressive strength was exhibited when SBR latex mixing rate was 9% and dropped by 8.6% compared to plain, but because it exceeds 28Mpa, it is a strength that meets quality standards of the Republic of Korea.

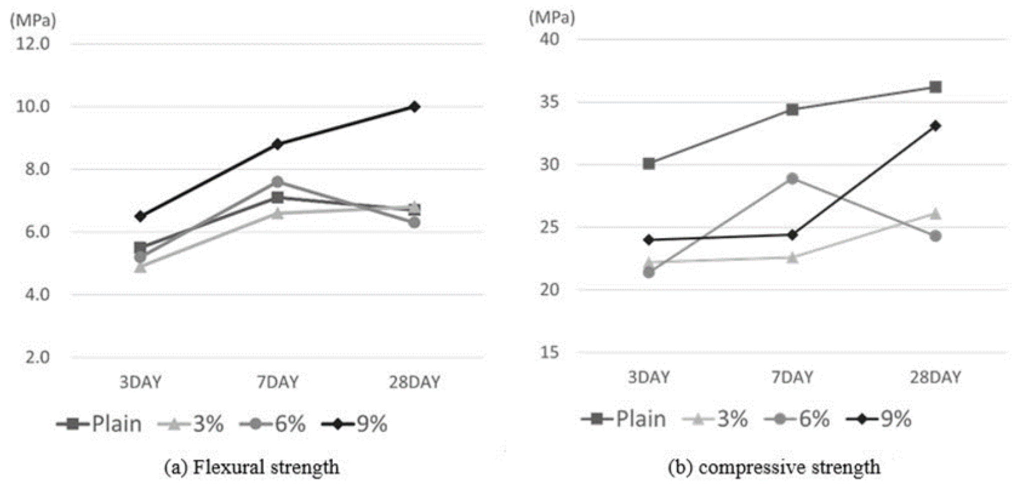

Fig. 2: Flexural strength and compressive strength according to SBR latex mixing rate

The panel quality standard of KS F 4735 is an absorption rate below 18%. Figure 3 is a graph showing the absorption rate measurement results through mixtures of Table 2. The average absorption rate of specimens of all mixtures meets quality standards, and when adding SBR latex, it showed a tendency for absorption rate to increase and then begin to decrease when the mixture rate grew. Figure (b) shows the results of fluidity tests. In the case of 9% SBR latex mixing rate having the highest slump value of 145.2mm, it displayed appropriate fluidity without material separation. Therefore, it is judged that the 9% SBR latex mixing rate with slump value for panel production that has the highest flexural strength and compressive strength is the most appropriate for panel production mixtures.

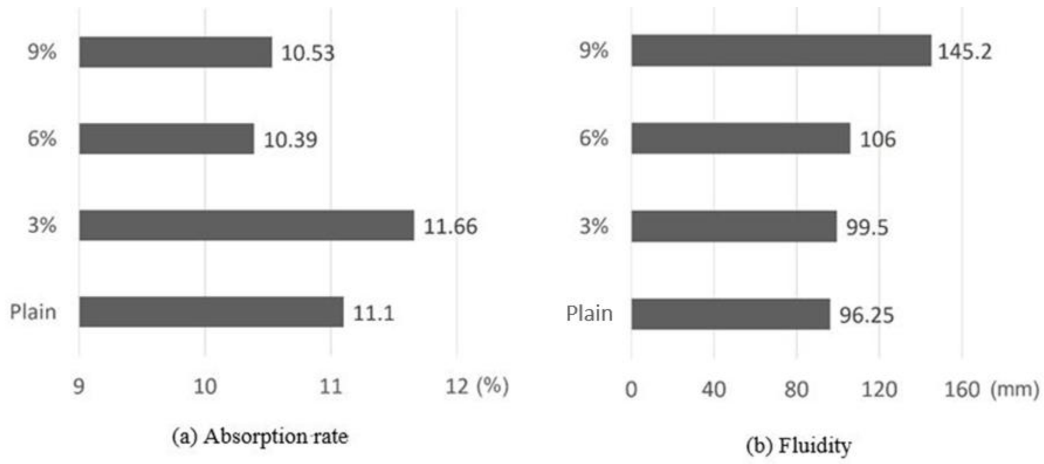

Fig. 3: Absorption rate and fluidity according to SBR latex mixing rate

4. Free Form Panel Production Using LMC

4.1. Production Process

The free form panel shape configuration test involved production at mixing ratio of SBR latex mixing rate of 9%, which showed the best performance through LMC performance tests. The dimensions on the plane are 500×500mm, and a 30mm displacement difference was given to the manual multi-point press to produce a free form silicon mold. Afterwards, cement mortar mixed at 9% SBR latex mixing rate was placed to produce the panel. Figure 4 shows the manual multi-point press device and Figure 5 shows setting the displacement using the manual multi-point press.

Fig. 4: Manual multi-point press device

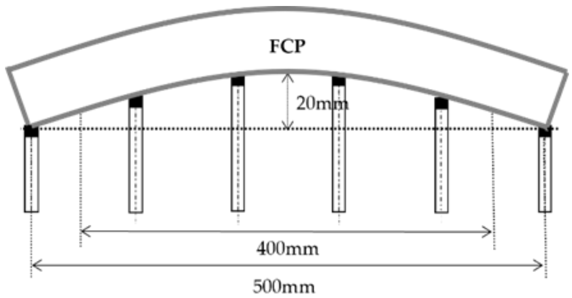

Fig. 5: Displacement settings of manual multi-point press device

4.2. Shape Error Analysis Method

In the case of shape error analysis, 100 points were randomly assigned in the 400x400mm section on the bulging side below the panel as shown in Figure 6. The shape produced with the measuring 3D scanner (Go! Scan Spark) and the quality inspection program VXInspect was used to compare the design shape and scan data shape.

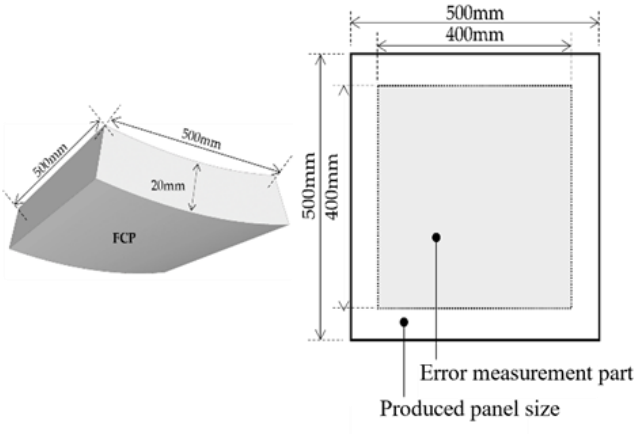

Fig. 6: Shape error analysis section

4.3. Test Results and Analysis

In the case of the free form concrete production sector, there are no precise regulations on production errors. Therefore, the error standard was set within 3% (3mm) of the wall thickness stated in the Korean architecture standards in this study. Figure 7 is the error value showing clear values among 100 random errors deduced through scanning.

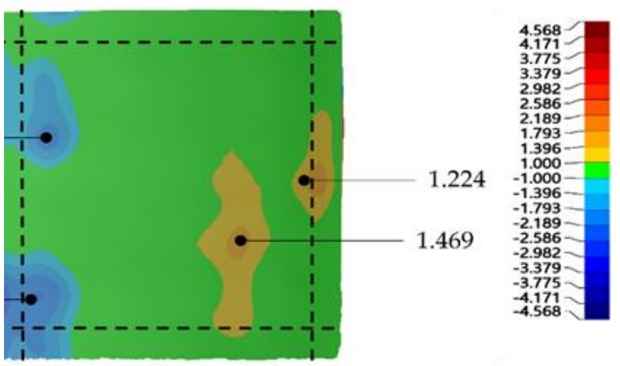

Fig. 7: Error value deduced by scanning

Results satisfying error standards in all points assigned with maximum value of 1.93%, minimum value of 0.004%, and average of 0.155% were deduced as shown in Table 2. This means that the mixing ratio for SBR latex mixing rate of 9% is appropriate for configuring the shapes of free form panels.

Fig. 7: Error value deduced by scanning

AVG	SD	Max.	Min.
0.155	0.821	1.930	0.004

5. Conclusion

This study used SBR latex as the admixture with the goal of improving flexural strength among performance of general concrete used in free form panels. LMC that uses SBR latex suppresses cracking, improves adhesive force, and enhances flexural strength and tensile strength. Accordingly, the optimal SBR latex mixing rate was deduced for producing free form panels through experiments in this study. Based on this, the following conclusions were derived through LMC free form panel shape configuration and error analysis.

1) Upon measuring the flexural strength and compressive strength in the materials performance test, it exhibited a tendency to grow the more SBR latex mixing rate increased, 9% at age of 28 days increased 148.1$ compared to plain, thus measuring the highest flexural strength. Compressive strength dropped by 8.6% compared to plain at 9% at the age of 28 days, but because it exceeded 28Mpa, it has a strength suitable to quality standards.

2) Upon measuring absorption rate and fluidity in the material performance test, the average absorption rate of specimens at all mixtures met the KS F 4735 panel quality standards, and when adding SBR latex, absorption rate increased, but when mixing rate grew, the absorption rate started to fall. In the case of fluidity, it was judged that 9% SBR mixing rate with slump value of 145.2mm for formability was the most appropriate.

3) Free form panels were produced with mixing rates for 9% SBR latex mixing rate that showed the best performance through fluidity, absorption rate, flexural strength, and compressive strength results. Values satisfying all points assigned with error rates at maximum value of 1.93% and average of 0.155% were deduced, and it was judged to be most appropriate for mixed free form panel shape configuration for 9% SBR latex mixing rate.

4) When producing free form panels through all test results, by using the 9% latex mixing rate, it was possible to obtain precise free form shape, while having higher flexural strength than previous. In addition, when mixing at higher than 9% SBR latex mixing rate through the results of this study, it is expected that flexural strength and compressive strength will be even further improved. Also, by additionally using water reducing admixtures or AE, it is expected that resistance to fluidity and material separate can be procured. It is judged that through this study and additional research, free form panel quality will be significantly improved.

6. Acknowledge

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2020R1C1C1012600).

7. References

1. Schipper, H.R. & Janssen, B. (2011). Manufacturing double-curved elements in precast concrete using a flexible mould: First experimental results. Czech Concrete

Society and fib-International Federation for Structural Concrete, 111. http://resolver.tudelft.nl/uuid:fc718916-cecf-42a8-a3d9-0bb8c2c8fe02

2. Lee, J.K. & Lee, K.B. (2011). A Study on Digital design process of the materialization of Free form Design Architecture. Journal of the Korean Digital Architecture Interior Association, 11(2), 13-19. http://ksci.kisti.re.kr/search/article/articleView.ksci?articleBean.atclMgntNo=DGCOB2_2011_v11n2_13
3. Lee, D.H. (2015). A study of construction and management technology of free-form buildings. Ph.D dissertation, Kyung Hee University, Seoul, Korea. http://dcollection.khu.ac.kr/jsp/common/DcLoOrgPer.jsp?sItemId=000000164730
4. Kim, S.W. (2009). Classification and Optimization of Irregular-Shaped Building Panels by Fabrication Methods : Focused on Dongdaemun Design Plaza and Park. Master's degree, Yonsei University, Seoul, Korea. https://dcollection.yonsei.ac.kr/public_resource/pdf/000000118206_20220221103421.pdf
5. Ryu, J.W. & Moon, J.S. (2013). A Study on Classification of the Panelizing for Architectural Freeform Surfaces and the Optimization of Panelizing. Journal of the Korea Academia-Industrial cooperation Society, 14(9), 4616-4626. https://doi.org/10.5762/KAIS.2013.14.9.4616
6. Oh, Y.G. & Jeong, K.T. & Lee, D.H. (2020). A Study on the Analysis of the Error Rate of Mixed Mortar Panel for Implementation Free-form Shape. Journal of the Korea Institute of Building Construction, 20(2), 155-162. https://doi.org/10.5345/JKIBC.2020.20.2.155
7. Lee, E.Y. & Kim, Y.S. (2014). An Analysis and Improvement of Free Form Building's Construction Productivity - Focused on Exposed Concrete Work -. Journal of the Korea Institute of Building Construction, 15(3), 38-46. https://doi.org/10.6106/KJCEM.2014.15.3.038
8. Kim, M.S. & Park, C.W. & Kim, K.H. & Do, S.L. & Lee, D.H. (2019). Proper Mixing Ratio for Securing Quality of Free-form Panel. Journal of the Korea Institute of Building Construction, 19(5), 449-456. https://doi.org/10.5345/JKIBC.2019.19.5.449
9. Lee, B.J. & Heo, H.S. & Lee, T.K. & Jeong, H.J. & Son, J.I. (2015). Latex Modified Mortar Characteristics by SBR Types. The Korea Institute For Structural Maintenance and Inspection, 19(1), 607-608. https://db.koreascholar.com/article?code=299537
10. Yoo, D.R. & Go, S.S. (2006). A Study on the Properties of Latex Modified Concrete using Recycled Coarse Aggregate. The Korea Institute For Structural Maintenance and Inspection, 10(5), 147-156. https://www.dbpia.co.kr/Journal/articleDetail?nodeId=NODE08852074
11. Choi, H.G. & Jung, E.H. & Kawg, E.G. & Kang, C. & Seo, J.P. & Kim, J.M. (2006). A Flexural Strength Properties of extruding Concrete Panel Using Stone Powder Sludge. Journal of the Korea Institute of Building Construction, 6(1), 115-118. https://kiss.kstudy.com/thesis/thesis-view.asp?key=3454342
12. Bae, B.I & Choi, H.K. & Choi, C.S. (2017). Experimental Study on the Shear Strength of Fiber Reinforced Ultra High Strength Concrete without Stirrups.

JOURNAL OF THE ARCHITECTURAL INSTITUTE OF KOREA Structure & Construction, 33(3), 3-12. http://www.dbpia.co.kr/journal/articleDetail?nodeId=NODE07131675

13. Yun, K.K. & Lee, J.H. & Kim, K.H. & Kim, D.H. (2000). Mechinical Properties of Latex Modified Concrete for Field Application. KOREAN SOCIETY OF CIVIL ENGINEERS, 1, 395-398. http://www.dbpia.co.kr/journal/articleDetail?nodeId=NODE01310550
14. F.A. Shaker & A.S. El-Dieb & M.M. Reda. (1997). Durability of Styrene-Butadiene latex modified concrete. Cement and Concrete Research, 27(5), 711-720. https://doi.org/10.1016/S0008-8846(97)00055-0
15. Choi, S.Y. & Choi, Y.S. & Yang, E.I. & Won, M.S. & Noh, J.H. (2013). Effect of Latex Mixing Ratio on Durability of Concrete. The Korea Institute For Structural Maintenance and Inspection, 17(1), 421-422. http://db.koreascholar.com/article.aspx?code=292187