Proceedings of the Fifteenth International Conference on
Computational Structures Technology
Edited by: P. Iványi, J. Kruis and B.H.V. Topping
Civil-Comp Conferences, Volume 9, Paper 14.2
Civil-Comp Press, Edinburgh, United Kingdom, 2024
ISSN: 2753-3239, doi: 10.4203/ccc.9.14.2

Recent Trends in Using Artificial Intelligence in Evaluating Functional Properties of Industrial Concrete Floors

M. Moj, S. Czarnecki and Ł. Sadowski

Department of Materials Engineering and Construction Processes, Faculty of Civil Engineering, Wroclaw University of Science and Technology, Poland

Abstract

Concrete floors are among the most commonly used solutions in industrial facilities. Their role is crucial during the operation of the facility hence the series of requirements that such a floor must meet. Ways of assessing the functional properties of concrete floors are often time-consuming and generate damage to the floor, which is in constant use. This article presents the main directions of interest related to the examination of concrete floors using non-destructive methods and artificial intelligence. Particular interest in prediction of concrete compressive strength and deficiencies in the comprehensive solution of concrete floor issues are noted. Research gaps were pointed out and potential directions for the development of activities related to modern solutions were identified, especially in the evaluation of functional properties of industrial floors.

Keywords: concrete floors, functional properties, prediction, machine learning, artificial intelligence, non-destructive testing methods.

1 Introduction

Surface-cured industrial floors are often used in large-scale industrial halls. Floors of this type are designed to meet the requirements of durability and comfort (Tab.1). It is believed that an industrial floor should maintain its properties for 25 years [1]. It is estimated that the share of expenditures incurred in the construction of a failure-free industrial floor is about 20% of the total costs associated with the construction of an industrial hall. Comparing the cost of floors [2], it can be concluded that the choice of floor finishing technology is mainly dependent on the price criterion . A concrete floor cured by the dry-on-wet method can be nearly half as expensive as resin-coated floors.

Any damage to floors in functioning factories forces very high costs associated not only with the repair of defective pavement, but also with the partial, periodic shutdown of certain areas of the plant, and leads to production downtime. Due to its exposure to various factors related to, among other things, stress [3]:

- mechanical like abrasion, overload, displacement, impact and fatigue,
- chemical like aggressive agents such as sulfates, salts, biological agents,
- physical such as freezing/thawing, thermal effects, shrinkage, erosion and wear,

it is necessary to ensure that the functional properties of the surface layers of industrial floors are adequate throughout its service life. Considering the damage presented (Fig.1) and scientific works [4][5], it can be concluded that the functional properties of floor surfaces are abrasion resistance and pull-off strength of the surface layer.

No.	Requirements	Standard
1	Adequate load capacity	EN 1991-1-1: Eurocode 1: Actions on structures
2	Crack resistance	EN 1992-1-1: Eurocode 2: Design of concrete structures
3	Scratch resistance	EN 13892-4 - Methods of test for screed materials - Part 4: Determination of wear resistance-BCA
4	Chemical resistance	EN 1504-9 - Products and systems for the protection and repair of concrete structures - Definitions, requirements, quality control and evaluation of conformity - Part 9: General principles for the use of products and systems
5	Impact resistance	EN 13892-8 - Methods of test for screed materials - Part 8: Determination of bond strength
6	Flatness of the surface	ASTM E1155-20 Standard Test Method for Determining FF Floor Flatness and FL Floor Levelness Numbers
7	Dust resistance	EN 15051-2 - Workplace exposure - Measurement of the dustiness of bulk materials - Part 2: Rotating drum method
8	Slip resistance	EN 13845 - Resilient floor coverings - Polyvinyl chloride floor coverings with particle based enhanced slip resistance - Specification
9	Abrasion resistance	EN 13892-3 - Methods of test for screed materials - Part 3: Determination of wear resistance.
10	Resistance to temperature changes	EN 13687-2 - Products and systems for the protection and repair of concrete structures - Test methods - Determination of thermal compatibility - Part 2: Thunder-shower cycling (thermal shock)

Table 1: Requirements for industrial floors.

The types of floors most commonly used in industrial facilities, based on articles [6][7], are dry shake topping (DST) surface-cured concrete floors. A critical component of any industrial floor is its top layer due to the significant differences in strength compared to the middle and bottom layers of the composite [8][9][10]. Figure 2 shows the layers of a concrete floor with a breakdown of the top layer exposed to external factors. Dry powder mixtures are used to reinforce the surface of the concrete floor. The sprinkles usually contain cement, quartz, pigments and chemical hardeners that react with the water in the concrete to cause faster curing of the surface and also to give a visual effect in the form of coloring or giving a shine. The DST method - dry shake topping - involves sprinkling dry powder of the curing mixture on the surface of the concrete floor while the concrete is still wet (in the process of setting). After the powder is applied, it is blended in with a troweling machine usually to a depth of up to 5-10mm. The curing mix reacts with the moisture in the concrete, causing an improvement in the surface properties of the concrete floor.

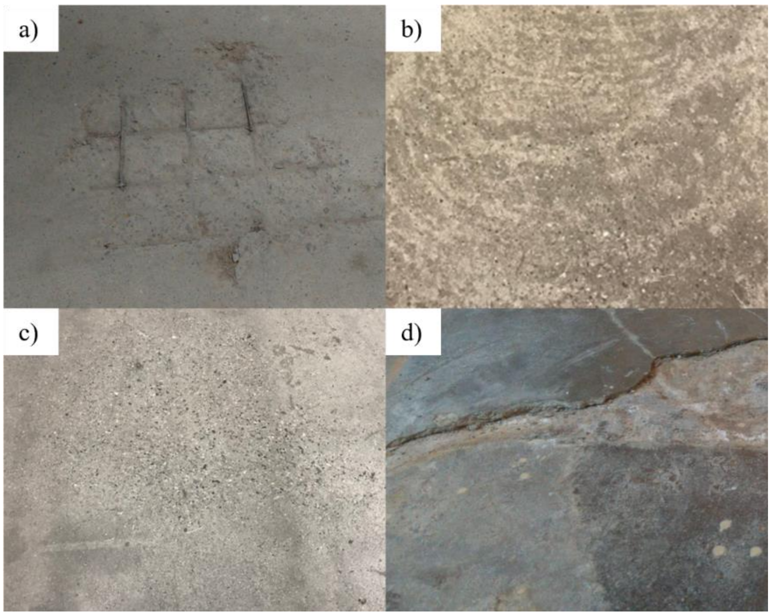


Figure 1: (a-d) Surface damage to concrete industrial floors.

To enforce confirmation of functional properties, it is necessary to use tests from the destructive or semi-destructive group. Abrasion testing can be performed using the BCA method according to PN-EN 13892-4, the RWA method according to PN-EN 13892-5 or the Boehme method according to PN-EN 13892-3. The RWA and Boehme methods require taking samples from the floor, which involves cutting holes in the finished concrete element . Similarly, the BCA method causes damage to the completed floor due to the formation of pits in the floor. Pull-off strength testing of the near-surface layer using the pull-off method also requires the tester to damage the floor in order to obtain results. Care must be taken to ensure an adequate number of measurements to make the test representative. An example of this is the pull-off method, in which it is necessary to take a minimum of 1 measurement per $3m^2$ of floor, which for a 20 x 60m hall gives 400 measurements. Assuming a test using 40 pulleys for measurements, this results in halting production in the hall for nearly a month.

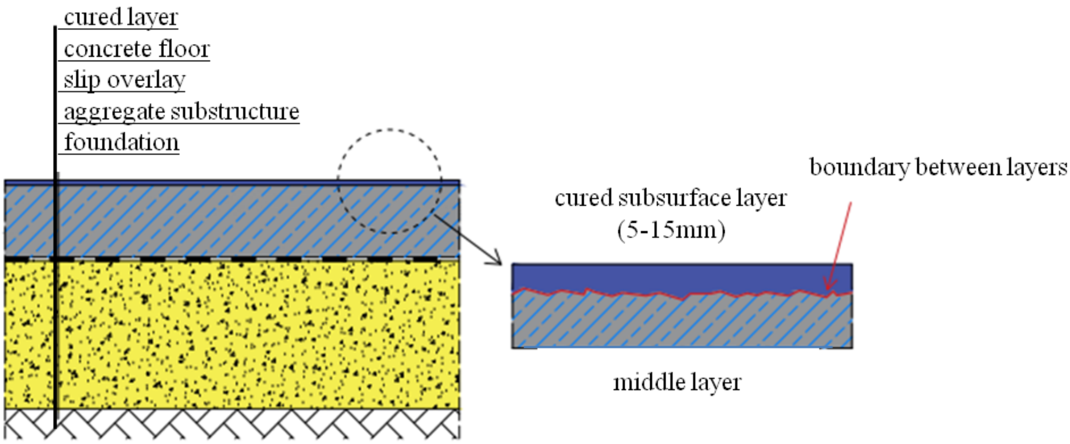


Figure 2: Section through an example of an industrial concrete floor with the division of the finishing layer due to differences in strength versus height.

In response to the tests presented here are complementary methods from the non-destructive testing department that evaluate often indicative values of strength properties. Acoustic methods such as ultrasonic wave velocity tests [11] and sclerometric methods such as the use of the Schmidt hammer [12] are used. In order to completely identify strength values using the aforementioned methods, it is also necessary to obtain boreholes for complementary laboratory testing which results in damage to the floor. In addition, studies of the surface morphology of the surface layer can also bring additional information about the functional properties of the floor. Work [13][14] indicates that it is possible to determine the functional properties of concrete floors using 3D laser scanning. Currently, artificial intelligence models assist civil engineers in solving problems. The scope of its applications is wide thanks to which it is also being used to modify ways of determining the mechanical properties of cementitious composites [15]. Machine learning already supports methods for determining compressive strength, among others [16]. Focusing on concrete floors, there are ways to determine the pull-off strength of the surface layer [17] and abrasion resistance [18][19].

2 Methodology

In order to determine the recognition of issues related to the evaluation of the functional properties of concrete industrial floors, keywords were analyzed on the Google Scholar search engine for scientific publications. Table 2 summarizes the results of the search phrases/keywords. After determining the results of the searches, it was decided to examine the results of the searches, also for the combination of phrases with the words: prediction, artificial intelligence and machine learning in order to determine what is the advancement of the application of modern capabilities in the given issues. The search was conducted on 23.02.2024.

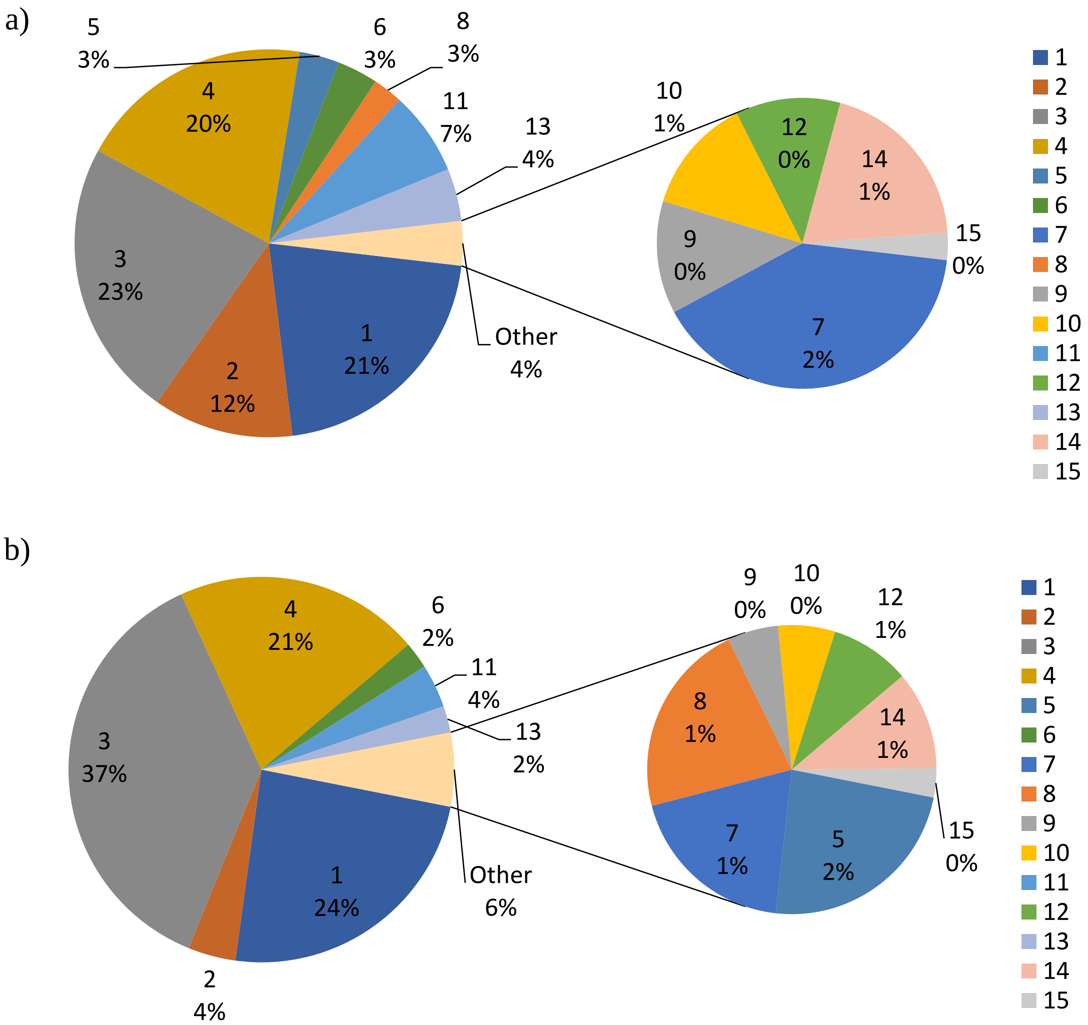
3 Results

The results of searches for keywords and phrases related to the given topic are summarized in Table 2. A pictorial representation of the results obtained is visualized in Figure 3. It can be seen that the vast majority of searches for the phrase concrete are related to concrete strength and concrete compressive strength. By far the fewest results were found for the phrases 9, 10, 12 and 15 which suggests insufficient recognition of the selected issues.

No.	Phrase/keyword	Google scholar			
		Search results [thousands]	Search results for the phrase added: [thousands]		
			prediction	artificial intelligence	machine learning
1.	floor	4350,00	2510,00	708,00	1180,00
2.	concrete floor	2400,00	418,00	234,00	380,00
3.	concrete	4760,00	3860,00	1780,00	2590,00
4.	concrete strength	4030,00	2150,00	759,00	1220,00
5.	morphology of the concrete surface	680,00	153,00	58,20	86,20
6.	concrete tensile strength	699,00	236,00	38,00	72,00
7.	functional properties of concrete floor	306,00	124,00	69,20	108,00
8.	surface curing of concrete	506,00	141,00	36,30	54,30
9.	abrasion resistance of concrete	95,10	36,80	21,90	28,10
10.	concrete floor surface scanning	97,70	41,20	29,20	52,10
11.	concrete compressive strength	1440,00	379,00	40,10	52,80
12.	surface layer of concrete industrial floor	88,40	57,90	33,50	58,20
13.	non-destructive	900,00	233,00	52,00	73,20

	testing methods				
14.	non-destructive testing tensile strength	149,00	71,40	20,60	26,50
15.	non-destructive testing abrasion resistance	22,90	20,90	8,27	16,40

Table 2: Summary of search results for phrases/keywords.



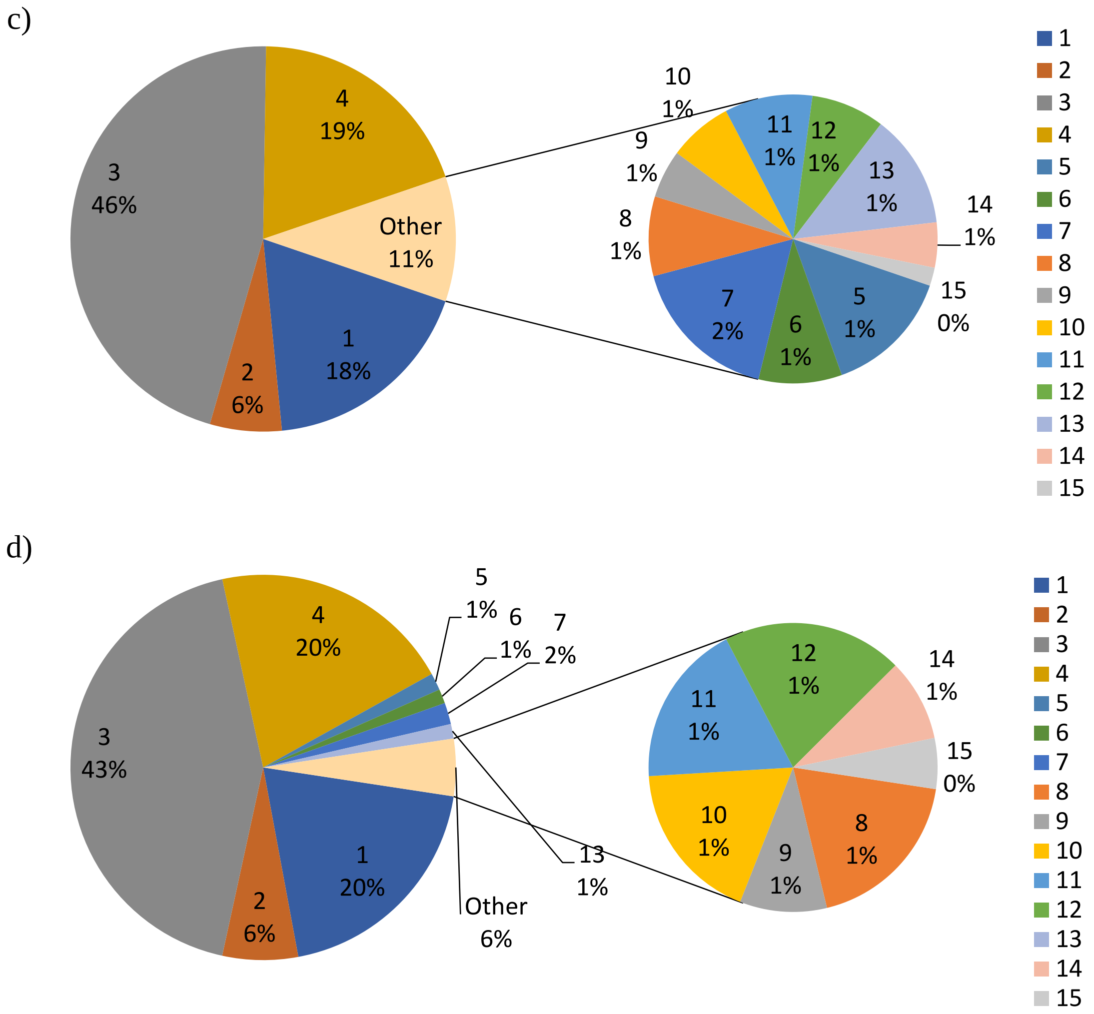


Figure 3: Pie charts of the number of results retrieved based on basic elements in each search engine: a) general, b) with "prediction", c) with "artificial intelligence", d) with "machine learning".

It should be noted that there has been an increase in the interest of new techniques and the desire for prediction in concrete-related topics. The distribution of the use of predictive technologies in the search results for the phrases: floor and concrete strength is similar to the results without the additional phrases. A decline in the use of modern solutions can be seen especially for the phrase "concrete floor."

4 Conclusions and Contributions

Noting the benefits associated with the use of machine learning and non-destructive methods in assessing the functional properties of concrete industrial floors, the validity of such solutions is indicated. Table 3 shows examples of the application of machine learning algorithms to predict selected properties of industrial floors.

No.	Requirements	Machine learning algorithm	Bibliography position
1	Adequate load capacity	AdaBoost	[20]
2	Crack resistance	Pixel Tracking Algorithm	[21]
3	Scratch resistance	no information available	
4	Chemical resistance	Random Forest, LightGBM, XGBoost	[22]
5	Impact resistance	SVM	[23]
6	Flatness of the surface	PointCNN	[24]
7	Dust resistance	no information available	
8	Slip resistance	Convolutional Neural Network	[25]
9	Abrasion resistance	ANN and Random Forest	[18]
10	Resistance to temperature changes	ANN	[26]

Table 3. The use of machine learning in determining floor requirements.

After analyzing the interest in the given topics, it can be concluded that the use of modern technologies in concrete floors is at a lower level than in related topics.
The large difference in interest in compressive strength compared to other properties of concrete and concrete floors suggests the omission of important issues in the subject of floors.
An important contribution to an adequate understanding and predictive capabilities in evaluating the functional properties of surface-cured floors is an adequate exploration of them. It is therefore reasonable to elaborate on the described issue.

References

[1] Hajduk, P. (2018). Projektowanie i ocena techniczna betonowych podłóg przemysłowych. Wydawnictwo Naukowe PWN.

[2] Drozd, W., & Kowalik, M. (2014). Współczesne posadzki przemysłowe. Przegląd budowlany, 85(7-8), 34-39.

[3] Hajduk, P. (2015). Przyczyny powstawania wad i uszkodzeń w podłogach przemysłowych. Przegląd Budowlany, 86(12), 42-48.

[4] Niedostatkiewicz, M., & Majewski, T. (2020). Uwarunkowania użytkowania podłóg przemysłowych. Błędy wykonawcze. Inżynier Budownictwa, 62-65.

[5] HULETT, T., & CLARKE, J. (2003). Technical report 34 concrete industrial ground floors: A guide to design and construction: Overview of the new report. Concrete (London), 37(2), 22-29.

[6] Świątek-Żołyńska, S., Majewski, T., & Niedostatkiewicz, M. (2020). Wybrane zagadnienia projektowania, wykonawstwa oraz użytkowania betonowych posadzek przemysłowych w aspekcie ich ścieralności. Przegląd budowlany, 91.

[7] Gmaj, I. (2019). Posadzki betonowe utwardzane powierzchniowo w centrach logistycznych. Autobusy–Technika, Eksploatacja, Systemy Transportowe, 227(1-2), 432-434.

[8] Stawiski, B. The heterogeneity of mechanical properties of concrete in formed constructions horizontally. Arch. Civ. Mech. Eng. 2012, 12, 90–94. 126
[9] Stawiski, B.; Radzik, Ł. Need to Identify Parameters of Concrete in the Weakest Zone of the Industrial Floor. IOP Conf. Series Mater. Sci. Eng. 2017, 245, 22063.
[10] Stawiski B.; Kania T. Examining the Distribution of Strength across the Thickness of Reinforced Concrete Elements Subject to Sulphate Corrosion Using the Ultrasonic Method. Materials 2019, 12(16), 2519
[11] Hameed, M. A. S., Maula, B. H., & Bahnam, Q. M. (2019). An empirical relationship between compressive strength and ultrasonic pulse velocity for concrete. Int. Rev. Civ. Eng, 10(6), 17061.
[12] Kumavat, H. R., Chandak, N. R., & Patil, I. T. (2021). Factors influencing the performance of rebound hammer used for non-destructive testing of concrete members: A review. Case Studies in Construction Materials, 14, e00491.
[13] Sadowski, Ł., Czarnecki, S., Krzywiński, K., Moj, M., Chowaniec, A., & Żak, A. (2022). Dry spinning wear of cementitious materials: A novel testing method and mechanism. Measurement, 196, 111216.
[14] Sadowski, Ł., Hoła, J., Czarnecki, L., & Mathia, T. G. (2021). New paradigm in the metrology of concrete surface morphology: Methods, parameters and applications. Measurement, 169, 108497.
[15] Marani, A., & Nehdi, M. L. (2020). Machine learning prediction of compressive strength for phase change materials integrated cementitious composites. Construction and Building Materials, 265, 120286.
[16] Czarnecki, S., Shariq, M., Nikoo, M., & Sadowski, Ł. (2021). An intelligent model for the prediction of the compressive strength of cementitious composites with ground granulated blast furnace slag based on ultrasonic pulse velocity measurements. Measurement, 172, 108951.
[17] Hossain, K. M., Anwar, M. S., & Samani, S. G. (2018). Regression and artificial neural network models for strength properties of engineered cementitious composites. Neural Computing and Applications, 29, 631-645.
[18] Czarnecki, S., Chajec, A., Malazdrewicz, S., & Sadowski, L. (2023). The Prediction of Abrasion Resistance of Mortars Modified with Granite Powder and Fly Ash Using Artificial Neural Networks. Applied Sciences, 13(6), 4011
[19] Malazdrewicz, S., & Sadowski, Ł. (2021). An intelligent model for the prediction of the depth of the wear of cementitious composite modified with high-calcium fly ash. *Composite Structures*, *259*, 113234.
[20] Feng, D. C., Liu, Z. T., Wang, X. D., Chen, Y., Chang, J. Q., Wei, D. F., & Jiang, Z. M. (2020). Machine learning-based compressive strength prediction for concrete: An adaptive boosting approach. *Construction and Building Materials*, *230*, 117000.
[21] Bazrafshan, P., On, T., Basereh, S., Okumus, P., & Ebrahimkhanlou, A. (2024). A graph-based method for quantifying crack patterns on reinforced concrete shear walls. *Computer-Aided Civil and Infrastructure Engineering, 39*(4), 498-517.

[22] Hosseinzadeh, M., Mousavi, S. S., Hosseinzadeh, A., & Dehestani, M. (2023). An efficient machine learning approach for predicting concrete chloride resistance using a comprehensive dataset. *Scientific Reports*, *13*(1), 15024.
[23] Haruna, S. I., Zhu, H., Jiang, W., & Shao, J. (2021). Evaluation of impact resistance properties of polyurethane-based polymer concrete for the repair of runway subjected to repeated drop-weight impact test. *Construction and Building Materials*, *309*, 125152.
[24] Li, D., Liu, J., Hu, S., Cheng, G., Li, Y., Cao, Y., ... & Chen, Y. F. (2022). A deep learning-based indoor acceptance system for assessment on flatness and verticality quality of concrete surfaces. *Journal of Building Engineering*, *51*, 104284.
[25] Deix, K., & Tutic, S. (2023). Determination of the slip resistance of interspersed synthetic resin flooring with a convolutional neural network. *Journal of Building Engineering*, *76*, 106721.
[26] Mukherjee, A., & Biswas, S. N. (1997). Artificial neural networks in prediction of mechanical behavior of concrete at high temperature. *Nuclear engineering and design*, *178*(1), 1-11.