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Application of Artificial Neural Networks to Predict the Compressive Strength of Rubberized Concrete: A Review

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Abstract: Waste rubber tires have been used in building materials to support the environment and green construction. There is a growing demand for rubberized materials as they are cost-effective and useful from a sustainable standpoint. There are several properties of the rubber tire that could be applied usefully such as low density, and waterproofing properties. Rubberized concrete has composed of waste rubber as natural aggregate and is an alternative solution to the use of tire rubber particles in the production of concrete. It has been proven that the addition of waste rubber tires to concrete starts to low strength and this restriction its application in structural elements but benefits to enhance the ductility, impact resistance, thermal conductivity, and acoustic properties. This paper presents a review of the recent studies on the application and development of artificial neural networks (ANNs) to predict the compressive strength of rubberized concrete. From this review, predicting the compressive strength of rubberized concrete by ANNs is generally more accurate, and their development is inexpensive and time-saving. In this review, the advantages, and limitations of ANNs to predict the compressive strength of rubberized concrete, as well as some new research trends have been addressed.

INTRODUCTION

Rubber is an important material that is used in a wide range of industrial products. One of these industries is automobile production, where rubber is utilized in a variety of applications such as rubber tires. Rubber tire production is estimated to be in the billions of units annually [1]. A large portion of this amount is just thrown away in landfills without treatment. Tire disposal in landfills takes up a lot of space. There is an urgent need to dispose of waste tires in a useful and environmentally sustainable manner. Moreover, large amounts of waste rubber bring many problems for the environment, and human health. From an environmental and economic standpoint, reducing the quantity of the car tire waste and recycling it, is very significant. It is essential that the vehicle tires be recycled and reused appropriately to protect natural resources. In the concrete industry, there is a growing demand for recycled materials. Since the natural resources have become inadequate for concrete production, an emphasis is being increased on the application of waste materials and the replacement of recycled aggregates such as recycled rubber.

Concrete is an essential building material, and simple to manufacture. Therefore, different research has been done to improve the technical qualities of concrete and make it cost-effective. In recent studies, industrial by-products have been utilized to develop the properties of concrete. The basic characteristics of rubberized concrete by replacing aggregates with rubber particles were the focus of early studies on the use of rubber in concrete technology. In order to reduce laboratory work and quickly estimate the compressive strength of rubberized concrete, numerous investigators have applied artificial intelligence techniques such as genetic algorithms, regression analysis, fuzzy logic, and artificial neural networks (ANN). Artificial intelligence techniques have been used to solve different civil engineering challenges in recent years [2-5]. Among these methods, ANN is a useful tool for predicting and developing relationships in complicated problems. ANNs have been successfully employed in concrete mix design for predicting the compressive, tensile, and flexural capabilities of rubberized concrete. There is not enough review research on the

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impact of combining rubber on the mechanical properties of concrete using ANNs and it is necessary to do an extensive review on this matter.

The purpose of this paper is to present a comprehensive review of the recent technical literature on the application of ANN as a strong machine learning technique to predict the compressive strength of rubberized concrete.

ARTIFICIAL NEURAL NETWORKS (ANNS)

This section presents the theoretical background and basic principles of ANNs. ANNs are a useful concept of natural neurons. An ANN can mimic a remarkable number of human brain functions, such as learning and generalizing from previous examples to generate accurate answers and solve new challenges [6,7]. ANNs could also be used to solve issues that do not have algorithmic methods or that have complex solutions. The fundamental architecture of an ANN contains an input layer, an output layer, and at least one hidden layer, as depicted in Figure 1.

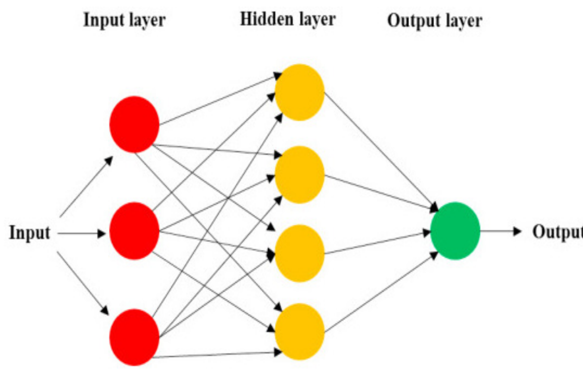

FIGURE 1. The basic architecture of an ANN model

The difference between the output of ANN and the target is called an error. The training of the network can take place in a supervised or unsupervised way to minimize the error. Among various ANN architectures, the backpropagation is the most common algorithm and has been applied in modeling to modify the weights of each layer in order to minimize the errors that appear at the network output [8-10].

In this section the influence of partial or full waste tire rubber replacement of natural aggregate on the compressive strength of concrete was investigated. From this overview, the compressive strength of concrete was highly dependent on the types and proportions of binders and aggregates.

AN OVERVIEW ON THE COMPRESSIVE STRENGTH OF RUBBERIZED CONCRETE

Concrete is a composite material made of cement, sand, and coarse aggregate that is used for structural and building purposes. Recently, rubber is also one of the decomposable materials which has a negative impact on the environment. The most important procedure that can be done to reduce the content of waste rubber products is the reuse of it. In this section, the general overviews of the mechanical properties of the rubberized concrete are reviewed. Rubberizing concrete can improve its characteristics such as durability, water absorption capacity, damping ratio, flexural strength, and crack resistance [11]. Based on this study, the compressive strength was decreased after the rubber was added to the concrete.

Addition of tire shreds in concrete can reduce the strength of the concrete [12]. The low strength of the rubber elements compared to the replacement coarse aggregates, along with inadequate bonding between the rubber and the cement paste, were the reasons for the drop in strength. The authors showed that the compressive strength was reduced by 58% more than flexural strength when coarse aggregates were substituted with rubber in concrete by 15%.

The application of tire rubber particles as a partial replacement of aggregates in concrete is investigated [13]. In this study, several experimental works for a variety of mechanical properties of concrete that contains rubber aggregate have been executed. The findings revealed that concrete containing more than 10% rubber aggregate will be unsuitable for structural elements. This research proved that rubberized concrete can be utilized in the construction of concrete slabs and precast concrete due to its smaller unit weight than conventional concrete. Concrete is the most common material in construction and for this purpose, a very large value of natural resources must be consumed. Therefore, the use of waste tires in concrete has become technologically feasible, and the resulting concrete is considered light. It was found that when the percentage of rubber in concrete is higher than a certain amount, the compressive strength of the concrete decreases.

Moving on, the compressive strength of concrete was tested on shredded and crumb tire materials [14]. The results revealed that by substituting 2.5% of the coarse aggregate with a shredded tire, the compressive strength of the concrete improved by 8.5%, while the compressive strength decreased at 5 % replacement and beyond. This indicated that the aggregate size and percentage of aggregate replacement have an important impact on the strength of the concrete.

In different research, the performance of concrete mixes containing 5, 7.5, and 10% waste tire rubber as aggregate and cement replacements was examined [15]. The obtained results demonstrated that replacing 5% of aggregate or cement with rubber resulted in a minor decrease in compressive strength, with no significant changes in other concrete qualities. For both grades of rubber used, the biggest reductions were related to 7.5 and 10% rubber replacement.

In recent research, a variety of rubber treatment techniques to develop the mechanical properties of rubber concrete is presented [16]. The compressive strength of concrete was obtained after substituting the aggregate and sand with rubber particles. After substituting the coarse aggregate with rubber, the compressive strength was reduced by up to 85 %. When sand was replaced with crumb rubber, the compressive strength was reduced by only 65%. It can be concluded that, despite the lower compressive strength of rubberized concrete compared to conventional concrete, there is a huge market for concrete products using rubber aggregates, which will make appropriate use of discarded rubber tires, which are a major source of pollution.

COMPRESSIVE STRENGTH OF RUBBERIZED CONCRETE USING ANNS

Artificial neural networks (ANNs) offer new advantages and opportunities and they have been used effectively in varied applications including the compressive strength of rubberized concrete. For example, a novel regression technique based on a combination of genetic algorithm and ANNs (GA-ANNs) to predict the compressive strength of rubberized concrete using the ultrasonic pulse velocity technique is developed [17]. In the said research, 158 datasets collected from previous studies have been used to train the network. These datasets include the information on mix design, type of cement, and contents of materials such as rubber, coarse and fine aggregate, curing condition and time, compressive strength, pulse velocity, and sample geometry. The results indicated that the GA-ANN was able to successfully predict the compressive strength with a high level of accuracy. Results supported that GA-ANNN has the maximum precision compared to regression methods. Based on this study, the curing time had more impact on ultrasonic pulse velocity readings.

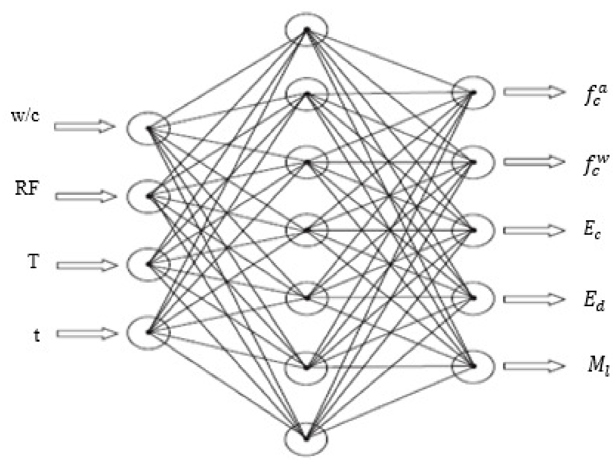

FIGURE 2. The architecture of ANN to predict the compressive strength of rubberized concrete [18]

In a recent study, a procedure to estimate the compressive strength of rubberized concrete subjected to elevated temperature using ANNs is presented [18]. In this study, the input datasets contain different fiber contents (RF), and six different levels of temperatures (T) with three display durations (t) along with three water-cement ratios. The output parameters were consisting of compressive strength of rubberized concrete for water-cooled (fwc) and air-cooled (fac), static and dynamic modulus of elasticity (Es, Ed), and mass loss (M_l). The architecture of ANN is depicted in Figure 2. From the sensitivity analysis, it was found that the temperature has the maximum influence on the compressive strength of rubberized concrete followed by various fiber content whereas, the water-cement ratio had a relatively lower impact. In this study, the durability properties of rubberized concrete exposed to elevated temperatures have not been considered.

Moving on, a method based on ANN and fuzzy logic to predict the material properties of rubberized concrete is developed [19]. In this study, waste vehicle tires were used in the production of rubberized concretes. A multilayer ANN with a backpropagation algorithm was employed to distribute the error of the ANN. The inputs of the network were cement, sand, water, fine crushed stone, coarse crushed stone, fine rubber, and coarse rubber. The concrete's unit weight (UW) and flow table (FT) were considered as the outputs of the ANN. The architecture of ANN is shown in Figure 3. According to the results of this study, it was proven that the properties of concrete could be found without doing any laboratory test by using ANNs. The results from the experiment were very similar to those of the ANN method. There have been errors of less than 10% between the output values and the experimental findings according to this study. The authors in a similar order [20] predicted the rubberized mortar properties employing ANNs and fuzzy logic. In this research, waste rubber was applied as sand to produce mortar. The flexural and compressive strength of mortar were considered as output of the network. In the procedure of training, time, cement, sand, fine rubber, coarse rubber, and water (W) were considered as inputs of ANN. From this study, it was concluded that the properties of rubberized mortar can be determined using ANNs and fuzzy logic techniques with a very high level of accuracy.

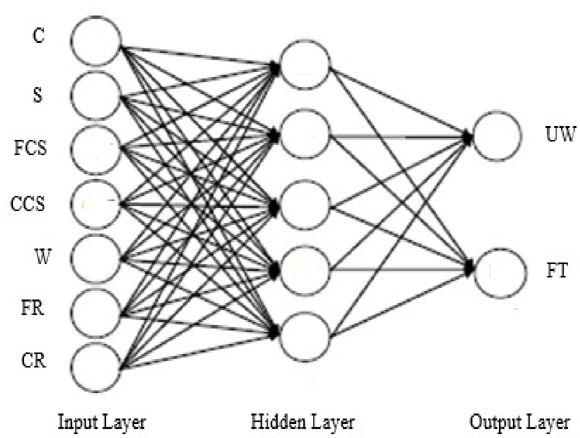

FIGURE 3. The architecture of ANN to predict the concrete's unit weight and flow table [19]

Recently, different mixes of rubberized concrete by incorporating the ground blast furnace slag (GBFS) using various percentages of discarded rubber tire crumbs (DRTCs) is studied [21]. The mechanical properties of the rubberized concretes were assessed using an ANN incorporated with the genetic algorithm (GA) and compared with the datasets from laboratory. In the said research, the compressive strength (CS), tensile strength (TS), and flexural strength (FS) of rubberized concrete were evaluated and the average value of three specimens at 3, 7, 28, 90, 180, and 365 days of curing age were prepared to assess the mechanical properties. From this study, the concrete mix prepared with DTRCs of 30% showed the highest compressive strength after 28 days of curing period. All the three material properties of rubberized concrete contain compressive, tensile, and flexural concrete were decreased with the increase of more than 30% of DTRCs content. Achieved results showed that the combination of genetic algorithm and ANN provided acceptable outcomes for the mechanical properties of the rubberized concrete.

In another research, a novel technique to predict the compressive strength of rubberized concrete by using a deep neural network model is purposed [22]. In this study, a rubber concrete is constructed using 12 input parameters consisting of binder, cement, cement replacement materials, specimen geometry, superplasticizer, water, water/binder, water/cement, fine and coarse aggregate, crumb rubber, and chipped rubber as input parameters of ANN. The compressive strength of rubberized concrete was considered as output, as shown in Figure 4. A deep ANN structure with the architecture of (12-16-14-3-1) was constructed and evaluated to validate the results.

The proposed network showed high reliability with a correlation of 99%. From the results of this study, it is claimed that the ANN model reveals very good accuracy in predicting the compressive strength of rubberized concrete according to the coefficient of correlation and root mean square error (RMSE).

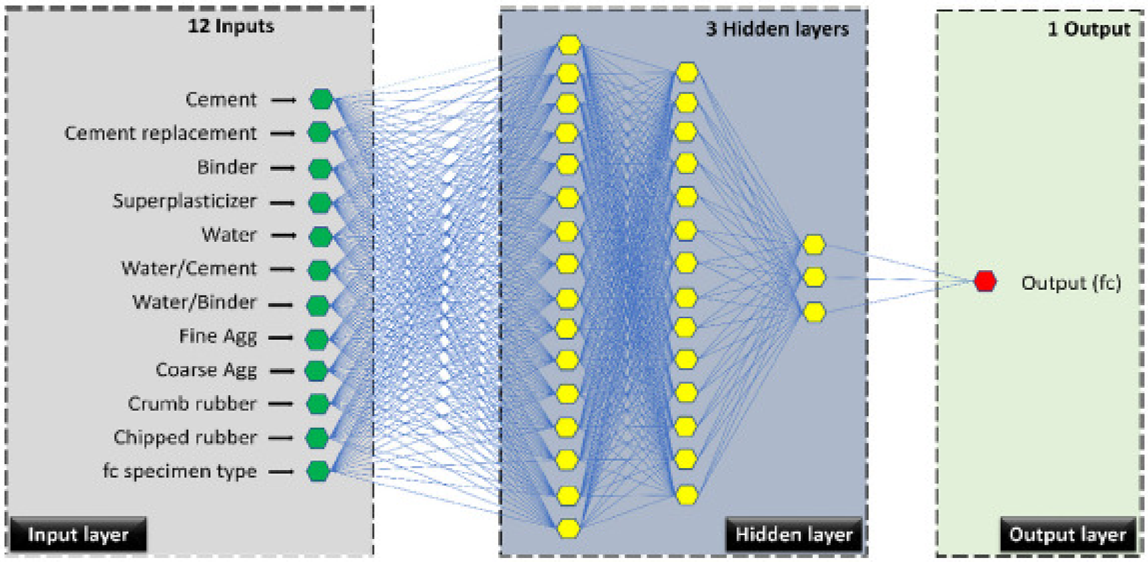

FIGURE 4. Deep neural network structure to predict the compressive strength of rubberized concrete [22]

A sensitivity analysis was implemented to show the impact of input parameters on the results. It was demonstrated that the crumb and chipped rubber have a negative effect on the results of compressive strength, while the volume of coarse and fine aggregates had a considerable impact on compressive strength.

In another study, the influence of using the waste rubber tire crumbs (WRTCs) on the strength performance of the alkali-activated rubberized concrete (AARC) is presented [23]. In this research, the waste rubber tire crumb was used as a partial substitution for the natural aggregates. The rubberized alkali-activated concrete was containing fly ash (FA) and ground blast furnace slag (GBFS). ANNs were carried out to assess the applicability of the rubberized concretes for the compressive strength, tensile strength, flexural strength, workability, and water absorption. From the results of this research, the alkali-activated rubberized concrete with 30% of waste rubber tire crumb demonstrated improved mechanical strength. The experimental results matched the results from ANNs and proved the ability of ANNs to predict the properties of alkali-activated concrete containing rubber with minimum error and a high value of correlation. Also, the suggested mixes were not expensive and environmentally friendly compared to the traditional concretes.

Moving on, an ANN to predict the compressive strength of concrete modified with NaOH treated crumb rubber is established [24]. In this study, concrete was formed by adding crumble rubber, resulting in lower greenhouse gas emissions, disposal costs, and building expenses, all of which support sustainable construction. The founded model could suggest a consistent base for growing the use of crumble rubber for construction activities.

In a research study, a novel method to predict the compressive strength, flexural strength, and tensile strength of polymer concrete composite with tire rubber powder using ANNs is presented [25]. In this research, ten experimental mixes were determined to obtain the values of mechanical properties by changes in the quantities of the tire powder. From the results of this study, the maximum compressive strength was achieved for 0.3 tire powder. Maximum tensile strength was obtained for experimental values of 0.17 tire powder. In this study, ANN generated the mixes with the lowest possible expense and maximum compressive.

In different study, a database containing 457 combinations in which aggregate was substituted with waste rubber to obtain the compressive strength of concrete using ANNs was created [26]. Several ANNs were developed for predicting the compressive strength of concrete using tire rubber. The findings of this research showed that a developed ANN with three hidden layers was the best network to predict the compressive strength of rubberized concrete as it has the greatest correlation value and the lowest root mean square error. Based on this study, it can be stated that the ANN model can be considered an alternate and effective method to predict the compressive strength of rubberized concrete.

In another study, a developed ANN was implemented to predict the compressive strength of rubberized concrete [27]. The obtained results from ANNs were compared to the database of 20 rubberized concrete experimental measurements to verify the model. The laboratory test included recycling 5, 10, 15 and 20% percentage of aggregate with various powder sizes of 0.2, 0.4, 0.6, and 0.8 mm of rubber. Results showed the high ability of ANN in the prediction of compressive strength of rubberized concrete compared to multilayer regression with a correlation coefficient of 0.965.

In another research, an ANN was applied to predict the compressive strength of rubberized concrete [28]. In this study, a model using ANN with three variables that were water/cement ratio, superplasticizer, and granular squeleton was built to predict the compressive strength of rubberized concrete as the output of ANN. The granular squeleton gathers fine aggregates, coarse aggregates, crumb rubber, and tire chips. The applicability of the model has been evaluated by using mean square error and correlation coefficient. The results revealed that ANN has the capability to estimate the compressive strength of rubberized concrete with satisfactory accuracy by utilizing new parameters. From this study, without doing any laboratory tests, the compressive strength of rubberized concrete can be predicted using ANN.

Also, in recent years, the interest of applying ANNs to predict compressive, tensile, and flexural strength of concrete has increased and several attempts have been made to estimate the material properties of concrete in civil structures using ANNs [29-36]. In this section, the research findings committed to determining the compressive strength of rubberized concrete have been discussed. From this overview, ANN has been demonstrated to give superior accuracy in predicting the compressive strengths of rubberized concrete.

CONCLUSION

The natural resources are restricted and usage of them must be preserved. On the other hand, waste rubber storage causes environmental pollution and endangers human health. One of the best solutions to overcome these problems is to combine the waste rubber and tire chips into the concrete and partially substitute natural aggregate such as fine and coarse aggregate. This ensures that both natural resources are preserved, and people's health is not endangered. Obtaining the compressive strength of rubberized concrete samples in the laboratory is time-consuming and costly. Recently, artificial intelligence techniques have been used to predict the compressive strength of concrete without laboratory work and using existing datasets.

ANNs are one of the most important artificial intelligence techniques that have been applied to predict the compressive strength of the rubberized concrete by many researchers. In this study, the literature of the recent studies utilizing ANNs to predict compressive strength of rubberized concrete have been reviewed.

Based on the statistical indicators such as correlation coefficient, and root mean square error, the performance of ANN models demonstrated an excellent prediction of compressive strength of rubberized concrete compared to the conventional methods.

Based on this review, the findings of ANNs were very similar to the laboratory results and showed that the addition of tire rubber to concrete leads to low compressive strength of rubberized concrete and this limits its use in structural applications but helps to improve the ductility, higher toughness, higher impact resistance, lower thermal conductivity, and higher noise reduction factor. According to the available literature, ANN is an efficient and cost-effective method for predicting the characteristics of the rubberized concrete. It is tremendously useful in situations when accurate and experimental setups need a lot of time and are expensive.

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REFERENCES

1. F. Elshazly, S. Mustafa and H. Fawzy, Egypt. J. Eng. Sci. Technol **30**(1), 1-11 (2020).
2. S.J.S. Hakim, J.M. Irwan, M.H.W. Ibrahim and S.S. Ayop, The Journal of Applied Research and Technology (JART) **20**(2), 221-236 (2022).
3. S.J.S. Hakim, S.N. Mokhatar, S. Shahidan, T.N.T. Chik, Z.M. Jaini, N.H. Abd Ghafar and A.F. Kamarudin, Civ. Eng. Archit. **9**(2), 523-532 (2021).

4. O. Avci, O. Abdeljaber, S. Kiranyaz, M. Hussein, M. Gabbouj and D.J. Inman, Mech Syst Signal Process **147**, 107077 (2021).
5. J. Ngudiyono, I.N. Fajrin and F. Merdana, Civ. Eng. Archit. **9**(6), 1717-1726 (2021).
6. M. Mohammadhassani, M.Z. Jumaat, M. Chemrouk, A. Ghasemi, S.J.S. Hakim and R. Najmeh, Procedia Engineering, **14**, 2141-2150 (2011).
7. S.J.S. Hakim, H.A. Razak, S.A. Ravanfar, Int. J. Damage Mech. **25**(3), 400-430 (2015).
8. S.J.S. Hakim and H. Abdul Razak, International Journal of Physical Sciences **6**(35), 7991-8001 (2011).
9. J. Noorzaei, SJS. Hakim and M.S. Jaafar, Indian Geotech. J. (IGJ) **38**(4) 4, 515-528 (2008).
10. J. Noorzaei, SJS. Hakim, M.S. Jaafar and A.A.A. Abang Ali, A.A., Thanoon, WAM, Indian Concr. J. **81**(8), 17-24 (2007).
11. A. Sayeed and M.K. Khan, Int. j. emerg. technol. eng. res. (IJETER) **6**(5), 13-17 (2018).
12. S. Mitoulis, A.R. Bennett, British Journal of Environmental Sciences **4**(4), 11-18 (2016).
13. S.J.S. Hakim, J. Noorzaei, M.S. Jaafar, M. Jameel, M. Mohammadhassani, International Journal of Physical Sciences **6**(5), 975-981(2011).
14. A.A. Samuel and S. Emmanuel, Int J Eng Res Appl. (IJERA) **39**(2), 1098-1101 (2013).
15. E. Ganjian, M. Khorami and A.A. Maghsoudi, Constr Build Mater. **23**(5), 1828-1836 (2009).
16. R. Roychand, R.J. Gravina, Y. Zhuge, X. Ma, O. Youssf, and J.E. Mills, Constr Build Mater. **237**, 117651 (2020).
17. Y. Zhang, F. Aslani, B. Lehane, Constr Build Mater. **307**, 124951 (2021).
18. T. Gupta, K.A. Patel, S. Siddique, R.K. Sharma, S. Chaudhary, Measurement **147**,106870 (2019).
19. I.B. Topcu and M. Sarıdemir, Constr Build Mater. **22**, 532-540 (2008).
20. I.B. Topcu and M. Sarıdemir, J. Mater. Process. Technol. **199**, 108-118 (2008).
21. A.M. Mhaya, G.F. Huseien, I. Faridmehr, A.R. Zainal Abidin, R. Alyousef and M. Ismail, Constr Build Mater. **295**, 123603 (2021).
22. H.B. Ly, T.A. Nguyen, H.V.T. Mai and V.Q. Tran, Constr Build Mater. **301**, 124081 (2021).
23. M.Y.M. Al-Fasih, G.F. Huseien, I.S. Ibrahim, A.R.M, H.A. Algaifi and R. Alyousef, Constr Build Mater. 303,124526 (2021).
24. P. Li, M.A. Khan, A.M. Galal, H.H. Awan, A. Zafar, M.F. Javed, M.I. Khan, S. Qayyum, M.Y. Malik and F. Wang, Chem. Phys. Lett. **793**,139478 (2022)
25. R.M. Diaconescu, M. Barbuta and M. Harja, Mater. Sci. Eng., **178**, 1259-1267 (2013).
26. M.H. Nyarko, E.K. Nyarko, H. Lu and S. Zhu, Eur. Phys. J. Plus **135B** (8), 1-23 (2020).
27. A. Abdollahzadeh,, R. Masoudnia and S. Aghababaei, WSEAS Transactions on Computers **10**(2), 31-40 (2011).
28. R. Bachir, A.M.S. Mohammed, T. Habib, Periodica Polytechnica Civil Engineering **62**(4), 858-865 (2018).
29. H.T. Thai, Structures **38**, 448-491 (2022).
30. M.M. Roberson, K.M. Inman, A.S. Carey, I.L. Howard and J. Shannon, Comput Struct. **259**, 106707 (2022).
31. A.M. Al-Sabaeei, A. Al-Fakih, S. Noura, E. Yaghoubi, W. Alaloul, R.A. Al-Mansob, M.I. Khan and N.S.A. Yaro, Constr Build Mater. **337**, 127552 (2022).
32. S.J.S. Hakim, M.H.W. Ibrahim, M. Mohammadhassani, Yeoh. D, Z.M. Jaini and T.N.T. Chik, Civ. Eng. Archit. **10**(4), 1564-1573 (2022).
33. K.B. Ramkumar, P.R.K. Rajkumar, N.A. Shaik, M. Jegan, Constr Build Mater. **261**, 120215 (2020).
34. W.B. Chaabene, M. Flah and M.L. Nehdi, Constr Build Mater. **260**, 119889 (2020).
35. S.J.S. Hakim, J. Noorzaei, M.S. Jaafar, M. Jameel and M., Mohammadhassani, International Journal of Physical Sciences **6**(5), 975-981 (2011).
36. S.J.S. Hakim and H. Abdul Razak, Res. J. Appl. Sci. **7**(9), 1750-1764 (2014).