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Original Article

Artificial Neural Network Predictions for Properties of Lightweight Concrete Incorporating Polystyrene Particles

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Abstract - *This study investigates the use of Expanded Polystyrene (EPS) particles in lightweight concrete to evaluate their compressive strength and density. The primary objectives are to assess the impact of varying EPS, cement, sand, and water proportions on these properties and to validate predictive models using Artificial Neural Networks (ANN). A dataset comprising 71 different mixes of concrete having strength up to 45 MPA from previous studies was utilized to build and train the ANN model. Moreover, an experimental program involved preparing and testing 120 different concrete mixes with various EPS contents was conducted. The results showed that increasing the cement content enhances both strength and density, while the higher EPS content provided a negative effect. A comparative study between the experimental results and ANN predictions revealed a close alignment, underscoring the ANN model's reliability and accuracy in predicting concrete properties, with an error margin of less than 1% and strong correlation coefficients of more than 94%. The findings highlight the potential of ANN for optimizing EPS lightweight concrete mix designs, providing a reliable alternative to extensive experimental testing.*

Keywords - *Lightweight concrete, Expanded Polystyrene (EPS), Compressive strength, Density, ANN.*

1. Introduction

The construction industry is continuously improving to address the challenges of modern Construction. Modern Construction requires the advancement of green, sustainable, efficient, and cost-effective construction materials. Sustainable Construction is achieved through the recycling of waste products, thereby decreasing the total density of the structures and enhancing the thermal properties by using EPS particles in lightweight concrete. This research also reduces material waste and trial experiments by giving a correct predictive model of mix optimization, thereby reducing the wastage of materials and improving eco-friendly construction activities.

Accordingly, lightweight concrete has emerged as an efficient material in concrete applications. The use of lightweight concrete can increase the efficiency of the structural design. This is true especially in high-rise buildings, bridges, and other long-span structures where weight is critical [1]. In such structures, lightweight concrete can lead to cost savings in the foundation and supporting elements. It also helps to improve the seismic performance of the structure. Moreover, it provides additional flexibility in the architectural design. Among the various types of lightweight concrete manufacturing agents, Expanded Polystyrene (EPS) stands out as a promising material. EPS is an inert, non-toxic, rigid, and closed-cell plastic foam. It has a low density and can provide high strength. EPS usually has a spherical shape and a density range between 10 and 20 kg/m3. EPS concrete can provide several advantages, including lightweight, high durability, enhanced thermal and acoustic insulation, enhanced shock absorption, and improved workability [2, 3]. Furthermore, the use of EPS in concrete aligns with sustainability requirements, as it can incorporate recycled EPS materials, reducing waste and environmental impact [4].

The total or partial replacement of the concrete's natural aggregate with EPS beads will produce lightweight concrete. Accordingly, concrete with a lower unit weight and strength will be achieved [5]. This is due to the EPS aggregate's lower unit weight, strength, and stiffness. The effects of EPS content as a replacement for concrete coarse aggregates have been investigated by many researchers. The physical and mechanical properties of fresh and hardened EPS concrete, including the workability, compressive strength, flexural strength, and density, were frequently evaluated. The results consistently reported a perceived decrease in the mechanical characteristics of the produced concrete [6]. This can be attributed to the nature of EPS beads when compared to the natural aggregate. EPS beads have low stiffness and strength and show a tendency to float and segregate owing to their low density. Such issues can be overcome by introducing pozzolanic materials such as fly ash or silica fumes. The incorporation of pozzolanic materials tends to increase the mixture viscosity and improve the interfacial transition zone between EPS beads and the cement paste [7-9]. Additionally, bonding additives like epoxy and ultra-fine materials can enhance EPS beads' dispersion within the concrete matrix [10]. The use of EPS beads in concrete enables the production of lightweight concrete with a density range from 300 to 2000 kg/m3 and strength that fits non-structural and structural concrete applications [8, 11]. Based on the 28-day compressive strength, the ACI PRC-213 [12] guide classifies the lightweight concrete into structural, medium strength, and isolation for the strength of ≥17 MPa, 7-17 MPa, and < 7 MPa, respectively.

The main factors influencing the properties of the produced EPS concrete are the EPS beads volume fraction, size and shape, strength and density, and surface treatment [13]. Increasing the volume of EPS beads to 40% is found to reduce the compressive strength by more than 70% [13, 14]. On the other hand, the smaller the EPS bead size, the higher the obtained strength; strength is reported to decrease by about 40% when the maximum bead size increases from 5 mm to 10 mm [15]. Research investigations revealed that the EPS concrete density is a significant parameter affecting concrete's mechanical properties, especially its compressive strength [16]. The higher the concrete EPS density, the higher the obtained strength [11, 17]. Interestingly, it is noted that the effect of EPS bead size diminishes as the EPS concrete density increases [15, 16]. Nikbin and Golshekan [13] have conducted a comparative analysis of the mechanical properties and the values of the fracture parameters of EPS concrete. They have used various percentages of EPS at various W/C ratios. The results showed that with increasing the volume fraction of EPS in concrete, the apparent density, tensile strength, compressive strength, elasticity modulus, fracture toughness, and the velocity of ultrasonic waves were decreased.

On the other hand, concerning the effects of EPS on the characteristics of aerated concrete, an enhancement in the compressive and flexural strengths, and the modulus of rupture was reported [18]. The obtained results of EPS aerated concrete fulfil the requirements for structural lightweight concrete. Wibowo et. al. [19] investigated the use of heat-treated EPS beads to enhance the mechanical properties of EPS concrete. The heat treatment of EPS beads improves the bond strength between the beads and the other concrete constituents compared to EPS beads without heat treatment. This has resulted in a considerable increase in the strength of the concrete that was produced. Applying a coating treatment could also enhance the bond strength between EPS and concrete. The use of SiO_2–TiO_2 coating to act as a fluidized bed in the photocatalytic reactor creates corrugated surfaces of the EPS beads and increases the bond between EPS beads and the other concrete constituents [20]. The resulting concrete is found to provide a strength sufficient for structural concrete applications. On the other hand, as compared to natural aggregate concrete and because of the inert nature of EPS, the EPS concrete provides better corrosion and chemical resistance [10]. Moreover, due to EPS energy absorption characteristics, EPS concrete can provide high fatigue resistance resulting from the dynamic cyclic or impact loads, making EPS concrete fit for military structures and road barriers [21, 22].

Based on the results of the aforementioned studies, the existing ordinary concrete models for predicting compressive strength may not be directly applicable to EPS bead concrete. This may be due to the different behaviours and failure patterns observed in EPS concrete compared to traditional concrete. By addressing the challenges of homogeneity and stability in EPS concrete, the overall reliability and acceptance of EPS concrete can be improved, resulting in a wider range of construction applications. The research associated with EPS lightweight concrete mostly concentrates on experimental research with small quantities of data and variables, so that knowledge of the joint influence of mix proportions on strength and density remains unfiled. In addition, there is a shortage of predictive instruments that reduce the number of experimental trials. The current study closes these gaps by establishing and training an ANN model to predict the lightweight concrete properties with EPS accurately.

There is a need to investigate the properties and the models available in this area to give accurate predictions for the various properties of EPS concrete. This paper is devoted to the experimental approach of the use of EPS particles in lightweight concrete and the main parameters, such as density and strength, which are the two factors that can influence the functionality of concrete structures. In addition to the experimental method, this research also employed the Artificial Neural Networks (ANN) capabilities for the prediction of compressive strength and density of EPS concrete while considering the various factors influencing its properties. ANNs are a sophisticated computational tool, but, at the same time, very revolutionary. Since using the experimental dataset to train the ANN, the intention is to come up with reliable predictive models to give quick and accurate concrete property estimates. The integration of ANN in this case also improves the design process's efficiency and minimizes the level of physical testing required, hence offering cost and time savings [23]. ANNs are used in concrete mix design to predict the concrete constituents' most appropriate material proportions; the cement, aggregates, water, and admixtures achieve the required performance characteristics such as strength, workability, and durability.

Mixing this wide-scoping experimental program with the powerful ANN model trained over a bigger and more heterogeneous dataset than other works is new. As compared to the previous study that relied on experimental trials or restrictive prediction models, the research assessed the overall impacts of the percentages of each of the materials on the strength, as well as the density and the study was able to predict the values with an accuracy of over 94%. Such an integrated methodology is a more reliable and generalizable method of optimizing EPS lightweight concrete mixes than what is in the current research. Though many studies have been conducted regarding the utilization of Expanded Polystyrene (EPS) particles in lightweight concrete, only a few of them were constantly involved with experimental assessment without the consideration of sophisticated predictive modelling, which is all discussed in the literature review. Thirty-seven sources are mentioned in the study.

This study combines the results from both experimental work and published work to validate the developed predictive models. This paper has also offered an in-depth examination of the implications of the introduction of EPS in terms of compressive strength and density, and at the same time, it has developed a reliable ANN-based predictive model. The work provides insight for practitioners on optimising EPS lightweight concrete mix designs by combining experimental data analysis with advanced modelling to cut down the dependency on time-consuming and expensive trials.

2. Materials and Methods

The research program of this study comprised data collected from both laboratory experiments and published literature. The available data from the literature was used to create the ANN model, and the data from the experimental work was used to validate the ANN model and verify its accuracy.

2.1. Dataset Collection

A literature review was conducted to collect published data on EPS concrete. The selected published work considers the coverage of concrete having various strengths that can be used for structural and non-structural applications. The collected data provides concrete with 28-day compressive strength ranging from 1 MPa to 45 MPa. Also, it considers the coverage of concrete having various densities that are suitable for lightweight concrete and normal-weight concrete applications. The collected data comprises concrete that has densities ranging from 300 kg/m^3 to 2200 kg/m^3. This range of densities includes the concrete used for insulation applications, too. By selecting this wide range of concrete densities, a wide range of aggregate replacements was involved, including EPS bead content up to 100% by volume. This diversity of information provides the base for understanding complex associations of constituent components as well as the effects of these associations on the measured properties. Table 1 summarizes the constituents and results of the collected dataset and the predicted values using the developed ANN model.

2.2. ANN Modeling

In constructing an Artificial Neural Network (ANN) model, some procedures should be followed to achieve a good model that can predict the measured response, including the compressive strength and densities of lightweight concrete with EPS particles. First, the design of the ANN architecture is done by defining the number of layers and how many neurons are present in each of them.

The input layer comprises the factors affecting the concrete properties: cement, sand, water, and Expanded Polystyrene (EPS). These inputs are passed through hidden layers that contain the set number of neurons utilizing an activation function that injects non-linearity into the model and allows the model to learn the relations within the data. The activation functions used were the sigmoid function, hyperbolic tangent function, and rectified linear unit function. These activation functions differ in the rate of convergence and in their non-linearity. The used activation functions are shown in Figures 1 and 2.

The ANN model has a feed-forward backpropagation structure with an input layer of four neurons (cement, sand, water and EPS content), optimized neurons in two hidden layers using the trial and error method and an output layer estimating the compressive strength and density. It trained an algorithm using the Levenberg-Marquardt and divided the data into 70 training set, a 15-validation set and 15 a 15-testing set. Activation functions (ReLU in hidden units and linear in output layer) were chosen to achieve the best convergence, and the model performance was measured by Mean Squared Error (MSE) and correlation coefficients (R^2).

After that, the ANN architecture is set, and then the model is created. This was accomplished using MATLAB software, which is also helpful in calculations and algorithm building. MATLAB contains the Neural Network Toolbox that allows for designing, training, and testing neural networks. The next step is data preprocessing, cleaning the input training data to match the desired standard. The network is then trained using the backpropagation algorithm to find the best weights/regression coefficients that connect neurons through channels to minimize the difference between the predicted and actual outputs.

The mentioned process is repeated multiple times until the desired or acceptable performance measures are obtained by the developed model. Figure 3 illustrates the methodological approaches applied in this research and briefly describes the major characteristics used in the Construction of the ANN model as a prediction tool. Moreover, the logical and organized approach shows the general plan of how the main objectives of this study would be achieved.

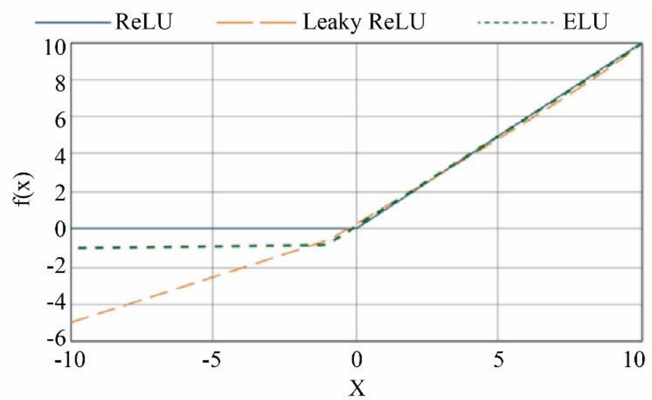

Fig. 1 ReLU, Leaky ReLU, and ELU activation functions

The use of MATLAB's visualization utilities helps to control the process of training, including the rate of learning, the number of epochs, and other factors of hyperactivity. To determine the generality of the model, the trained model is tested on a different set of data from the one used during the training. The use of the ANN model in MATLAB enables a reliable prediction of the different properties of the lightweight concrete to give a successful model, as recognized from the software's increased computational and graphical abilities.

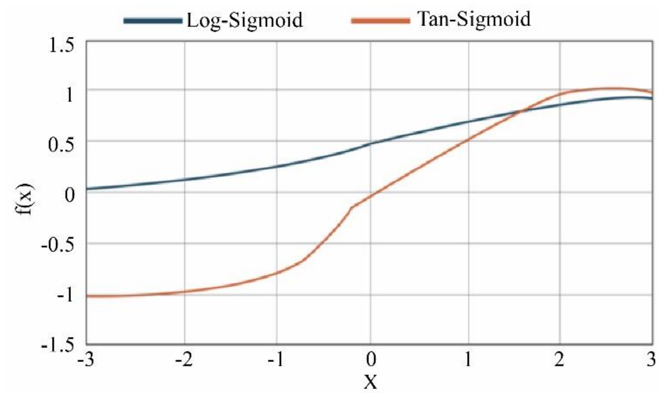

Fig. 2 Log-sigmoid and Tan-sigmoid activation functions

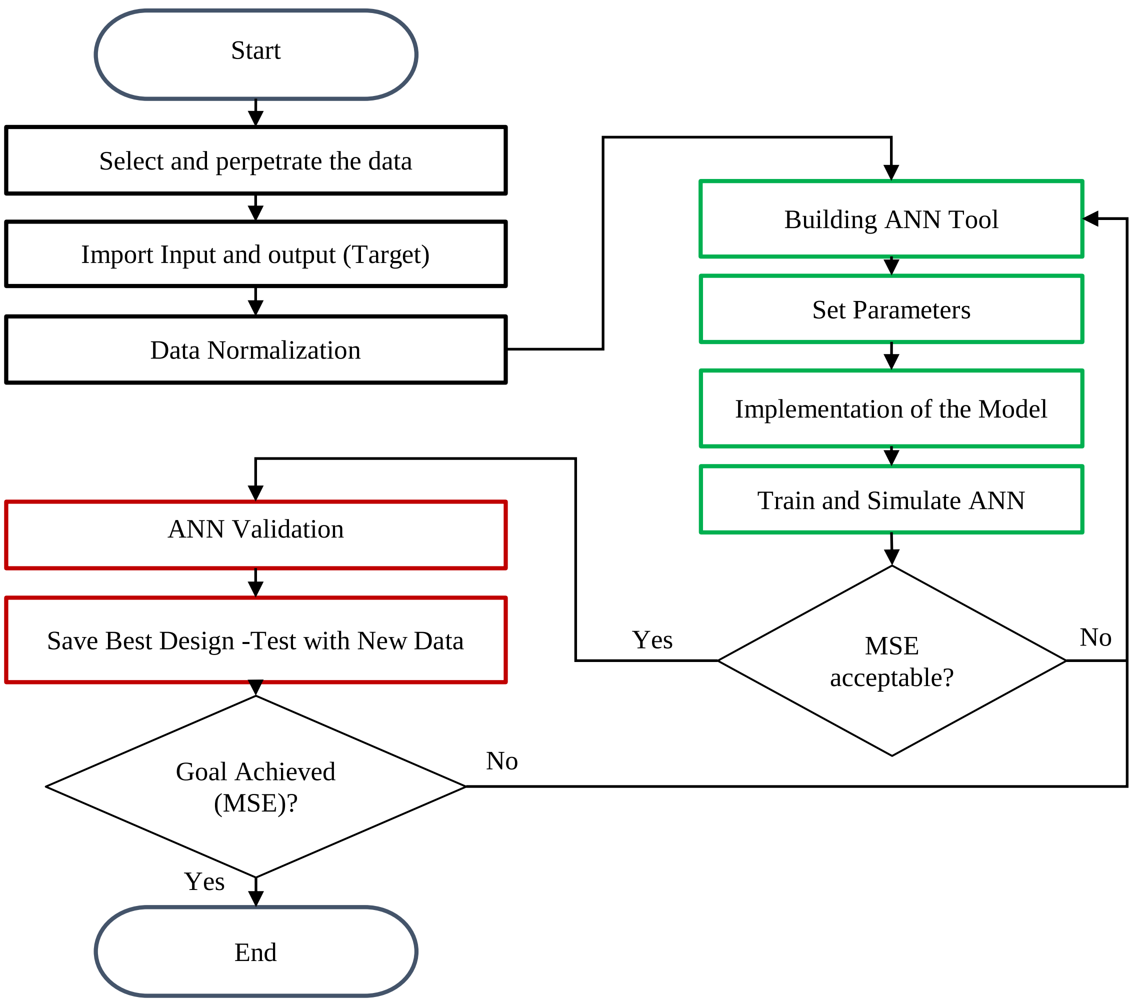

Fig. 3 Flowchart of ANN model building, training and testing

Table 1. Dataset of EPS concrete mixtures and the values of their measured and predicted properties

Ref.	Cement (Kg/m^3)	Sand (Kg/m^3)	EPS (Kg/m^3)	Max EPS Diameter (mm)	Water (Kg/m^3)	Experimental Results		ANN Predictions	
						Strength (MPa)	Density (Kg/m^3)	Strength (MPa)	Density (Kg/m^3)
[24]	238	761	7	3	95	3.5	1600	3.52	1585
	242	581	9	3	97	2.8	1460	2.83	1437
	250	696	10	3	100	4.1	1360	4.17	1325
	250	557	12	3	100	3.0	1220	2.98	1201
	256	513	9	3	103	2.1	1385	2.15	1355
	256	513	9	3	103	5.4	1385	5.44	1347
	256	513	9	3	103	5.4	1385	5.16	1337
	270	337	11	3	108	4.1	1140	4.03	1121
	285	356	10	3	128	5.3	1175	5.11	1156
	285	379	10	3	114	3.7	1180	3.68	1159
	285	356	10	3	128	4.9	1175	5.1	1161
	292	350	11	3	117	3.9	1250	3.87	1233
	294	588	8	3	118	6.5	1540	6.46	1522
	300	380	14	3	120	4.2	1200	4.22	1183
	300	333	15	3	120	3.2	980	3.16	971
	327	327	10	3	131	6.1	1220	6.05	1198
	327	327	10	3	131	6.0	1220	6.06	1198
	332	416	9	3	150	7.3	1330	7.25	1317
	334	478	9	3	134	7.8	1450	7.69	1422
	347	288	10	3	139	5.6	1210	5.55	1198
	350	508	11	3	140	13.5	1475	13.44	1455
	380	457	8	3	152	7.5	1460	7.32	1189
	386	483	8	3	155	6.5	1500	6.34	1475
	389	276	10	3	156	8.3	1212	7.55	1192
	389	276	10	3	156	6.8	1212	7.66	1192
	391	391	8	3	176	7.6	1344	7.43	1491
	400	604	9	3	160	11.6	1520	11.32	1491
	400	483	11	3	160	7.3	1300	7.21	1276
	400	403	12	3	160	7.0	1238	6.79	1221
	450	328	12	3	180	8.7	1200	8.59	1181
	489	367	8	3	196	5.7	1131	5.51	1113
	500	543	8	3	200	13.0	1548	12.65	1524
	550	410	9	3	220	15.4	1430	14.37	1411
	600	385	9	3	240	6.0	1270	5.43	1256
[25]	233	1246	2.88	4	134	3.4	1606	3.11	1586
	260	979	9.02	4	156	2.1	1404	2.21	1387
	272	528	15.67	4	163	1.1	978	1.01	967
	223	28	17.42	4	134	0.3	402	0.28	395
	199	0	15.86	4	120	0.3	335	0.29	321
[26]	798.29	652.31	2.64	5	270.27	46.3	1978	44.98	2005
	654.39	534.73	5.76	5	221.47	23.6	1626	22.79	1601
	516.44	421.98	8.76	5	174.96	20.3	1287	19.54	1266
	422.52	345.33	10.90	5	143.03	12.2	1057	11.84	1045
	791.84	646.76	2.47	5	267.97	37.8	1962	36.87	1943
	651.57	532.43	5.18	5	220.52	17.4	1618	16.98	1620
	516.26	421.80	7.80	5	174.86	11.6	1286	10.97	1301
	424.05	346.56	9.59	5	143.56	7.5	1059	7.41	1065
[27]	320	1344	6.88	4	192	11.60	2050	11.23	2085
	320	768	13.76	4	192	6.45	1800	6.13	1837
	320	0	22.93	4	192	3.95	1250	3.75	1271

[28]	400	783	6	5	196	29.6	1585	28.12	1566
	400	716	9	5	196	24.5	1455	23.55	1433
	400	617	13.5	5	196	20.2	1368	18.98	1342
	400	517	20.25	5	196	17.3	1276	16.65	1255
[8]	401	643.0	2.0	10	180	13.6	2295	12.37	2243
	401	643.0	4.0	10	180	10.88	1984	10.11	1952
	401	643.0	6.0	10	180	4.08	1635	3.88	1611
	401	643.0	8.0	10	180	3.86	1422	3.71	1398
	401	643.0	10.0	10	180	1.96	1086	1.85	1067
[18]	350	700	1.75	3	192	27.50	1865	25.99	1846
	350	700	3.50	3	192	26.90	1805	27.65	1788
	350	700	5.25	3	192	26.10	1762	27.67	1743
	350	700	7.00	3	192	25.00	1708	25.66	1688
	350	700	8.75	3	192	24.15	1648	24.65	1623
	350	700	10.5	3	192	22.45	1600	21.98	1578
	350	700	12.25	3	192	20.00	1480	20	1465
	350	700	14.00	3	192	18.37	1412	17.96	1401
[2]	517	1045	8.5	10	275	10.2	1609	9.78	1581
	414	1149	8.5	10	275	12.0	1577	11.63	1551
	362	1200	8.5	10	275	7.9	1563	7.68	1546
	388	1174	8.5	10	275	12.8	1576	11.99	1548

2.3. Experimental Program

2.3.1. Materials

This study conducted different lightweight concrete mixes using polystyrene, sand, cement, and water in the laboratory. The fine aggregate used was natural sand with a maximum particle size of 4.76 mm, a fineness modulus of 2.79, specific gravity of 2.65, and absorption of 3.0%. Fine aggregate satisfies the ASTM C33 [29] requirements for aggregate grading. Ordinary Portland Cement (OPC) Type I satisfies the required composition and strength characteristics in accordance with the ASTM C150 [30]. To produce lightweight concrete, the natural aggregate was replaced at various percentages with EPS beads. The used EPS beads are graded from 3 mm to 10 mm. The used EPS aggregate was produced directly from row spherical bodies of polystyrene containing an unleashing agent. These glossy beads were heat-treated by exposure to live steam. After the heat treatment, the EPS beads have softened and expanded to take up a cellular structure. These beads are non-elastic and may not return to their previous size even after applying a force; they can endure concrete mixing and compaction.

The experimental plan involved casting, curing, and testing of 360 specimens. The specimens were divided into five groups (A, B, C, D, and E) with respect to the weights of the components. Different concrete mixes were produced by varying the blending ratios of the constituents as given in Table 2. The cement content was varied in the range of 200 to 500 kg/m3, and the water-cement ratio (w/c) was kept constant at 0.5. This w/c ratio was selected to provide the correct consistency for proper workability and sufficient water content to facilitate hydration and strength development. The EPS content ranged from 1 to 15 kg/m3. The mixing and casting procedures followed the standard procedures described by the ASTM C192 [31]. The compressive strength test was conducted using concrete cubes of 100 mm length conforming to the ASTM C39 standards [32], while the density test was conducted according to ASTM C138 standards [33]. Concrete cubes were moist-cured and tested at 28 days of age. At least three cubes were tested for each concrete mix, and the average results were recorded. The results of the experimental program and ANN model prediction are also given in Table 2.

3. Results and Discussion

3.1. ANN Model

ANNs were used to predict the density and compressive strength of the lightweight concrete containing EPS beads. The ANN model was trained using the experimental dataset collected, as given in Table 1. The connections between the particulars of the input parameters (cement, aggregate, water, and EPS) and the output characteristics (density and compressive strength) were fully considered. After training the ANN model, the forecast yield was validated with the actual experimental outcome to assess the model's credibility. The predicted density and compressive strength values are presented in Table 1.

The results of the employed ANN were considered satisfactory; hence, the training and the validation Mean Square Error (MSE) curves have reduced gradually and reached the stability points as shown in Figure 4. The fact that the detail of one curve is barely distinguishable from the other exposes that overfitting did not occur and that only carefully chosen training and validation specimens can produce good outcomes.

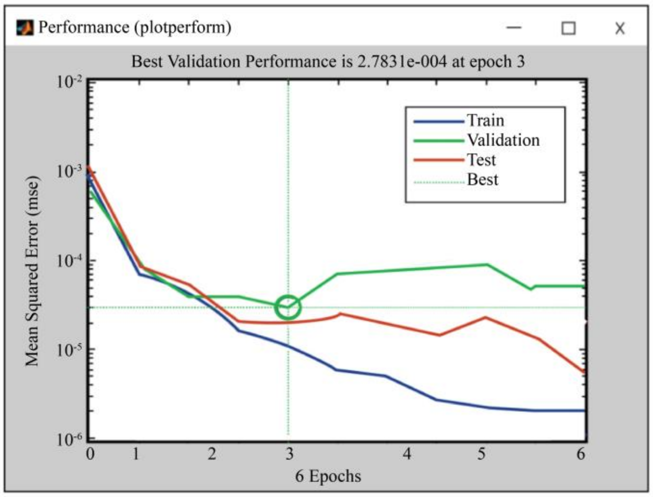

Fig. 4 The ANN performance indicators

The comparison between predicted and experimental results indicates that the present model, designated as the ANN model, had an extremely precise and highly accurate performance; the figures obtained by the estimated values were almost close to the experimental one.

Figures 5 and 6 illustrate the difference between the experimental and the ANN-predicted values of the compressive strength and density of the lightweight concrete that contains EPS polystyrene beads.

Figure 5 concerns the compressive strength and encompasses the experimental outcome as well as the ANN predictions. The figure shows highly correlated data points, which confirm that the proposed ANN model has correctly predicted the position and degree of dependency between the input variables and the compressive strength. Hence, it can be noted that there is a very minimal and negligible error, proving how accurate and tightly knitted the model is.

Likewise, Figure 6 depicts the density values, which show the excellent agreement between the experimental values and the values predicted by the neural network. As seen from the two sets of data, the model's high accuracy in predicting concrete density through the mix proportions testifies to the ANN model.

The highly comparable trends in both figures, where the ANN model's output points are virtually identical to the corresponding experimental values, attest to its reliability in predicting the concrete properties, affirming that the model possesses the potential to become an effective tool for future work in the optimization and design of EPS lightweight concrete mixes.

This strong agreement also shows that the ANN model can greatly minimize the number of physical experimentations required, thus making the process of designing EPS lightweight concrete less time-consuming.

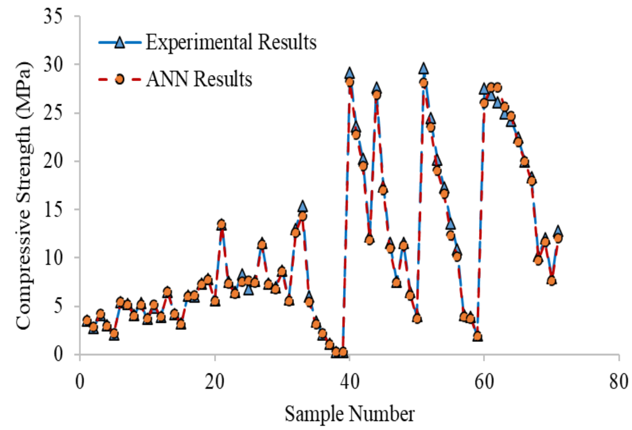

Fig. 5 Experimental and ANN predicted values of the compressive strength of concrete

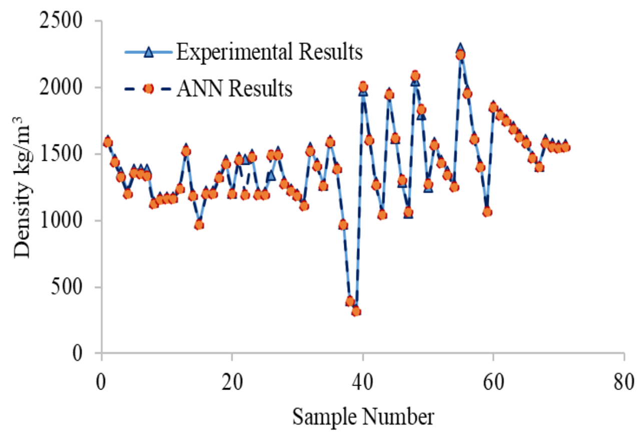

Fig. 6 Experimental and ANN predicted values of concrete density

3.2. Experimental Work

The experimental program results demonstrated a significant variation in the compressive strengths and densities of lightweight concrete incorporating EPS polystyrene beads. The obtained values for the compressive strength varied between 1.42 MPa and 18.23 MPa, while the concrete density ranged between 967 kg/m³ and 2087 kg/m³.

The analysis of obtained values was followed by a more detailed examination of the results of the study of dependencies between the density of the substance, the share of cement and EPS in the mixture, and the compressive strength of the obtained material. The obtained data demonstrates that as the cement content increased, the value of the concrete compressive strength also augmented.

This has always been triggered by the role played by cement as a binder, whose addition reinforces the concrete matrix and hence increases its load-carrying capacity. A higher cement content positively affects the denser and more stable Construction of the microstructure, which in turn results in higher compressive strength.

Table 2. Details of EPS concrete mixtures and the experimental and ANN predicted results

ID	Cement (Kg/m³)	Sand (Kg/m³)	Max EPS Diameter (mm)	EPS (Kg/m³)	Experimental Results		ANN Results	
					Strength (MPa)	Density (Kg/m³)	Strength (MPa)	Density (Kg/m³)
Group #A1	200	700	6	1	7.18	1725	7.32	1710
				3	6.44	1655	6.75	1638
				6	5.45	1595	5.65	1562
				9	4.25	1398	4.22	1369
				12	3.21	1268	3.31	1247
				15	1.95	1196	2.06	1172
Group #A2	200	600	6	1	6.64	1685	6.72	1667
				3	5.71	1595	5.83	1577
				6	4.83	1439	4.78	1422
				9	3.65	1358	3.51	1326
				12	2.45	1255	2.55	1235
				15	2.13	1147	2.03	1139
Group #A3	200	500	6	1	6.12	1648	6.23	1629
				3	5.57	1567	5.78	1546
				6	5.19	1471	5.33	1455
				9	4.81	1385	4.92	1362
				12	3.72	1236	3.85	1218
				15	2.69	1155	2.75	1136
Group #A4	200	400	6	1	4.98	1544	5.09	1524
				3	4.13	1368	4.09	1342
				6	3.41	1266	3.38	1249
				9	2.65	1211	2.56	1188
				12	2.23	1167	2.21	1150
				15	1.67	1089	1.69	1071
Group #A5	200	300	6	1	4.35	1425	4.45	1398
				3	3.48	1355	3.54	1332
				6	2.51	1254	2.59	1233
				9	2.06	1135	2.01	1129
				12	1.67	1098	1.69	1069
				15	1.42	986	1.39	967
Group# B1	300	700	6	1	8.93	1916	9.01	1889
				3	7.21	1854	7.33	1832
				6	6.23	1768	6.34	1748
				9	4.95	1655	5.11	1632
				12	4.31	1499	4.46	1471
				15	3.55	1442	3.65	1426
Group# B2	300	600	6	1	7.88	1881	7.96	1865
				3	7.35	1765	7.54	1749
				6	7.54	1571	7.63	1559
				9	6.45	1448	6.65	1439
				12	4.33	1412	4.47	1389
				15	3.12	1385	3.19	1368
Group# B3	300	500	6	1	6.85	1811	6.78	1789
				3	6.11	1766	6.23	1746
				6	5.23	1587	5.33	1569
				9	4.92	1495	5.09	1471
				12	4.34	1421	4.56	1411
				15	3.67	1365	3.87	1351
Group#	300	400	6	1	6.44	1745	6.55	1728

B4				3	5.68	1667	5.69	1649
				6	4.53	1577	4.67	1552
				9	4.14	1452	4.21	1438
				12	3.56	1355	3.71	1329
				15	3.10	1195	3.08	1176
Group# B5	300	300	6	1	5.41	1711	5.32	1689
				3	5.01	1598	5.21	1576
				6	4.66	1465	4.77	1443
				9	4.03	1322	4.09	1304
				12	3.85	1241	3.98	1226
				15	2.65	1082	2.55	1067
Group# C1	400	700	6	1	16.21	2204	16.98	2189
				3	14.87	2055	15.09	2038
				6	13.21	1877	13.33	1866
				9	12.43	1689	12.56	1668
				12	10.28	1545	10.20	1527
				15	8.22	1433	8.32	1419
Group# C2	400	600	6	1	12.8	2185	12.98	2167
				3	10.88	1984	11.06	1965
				6	8.08	1735	8.25	1721
				9	5.86	1572	5.97	1557
				12	3.96	1495	4.13	1479
				15	2.26	1325	2.31	1304
Group# C3	400	500	6	1	10.31	2077	10.52	2058
				3	8.27	1917	8.39	1891
				6	6.77	1765	6.87	1749
				9	5.83	1525	5.98	1508
				12	5.18	1326	5.31	1309
				15	3.85	1295	4.06	1279
Group# C4	400	400	6	1	7.95	1925	8.21	1902
				3	6.48	1765	6.65	1746
				6	5.45	1566	5.45	1543
				9	4.59	1474	4.68	1459
				12	4.15	1365	4.23	1345
				15	2.97	1226	3.06	1206
Group# C5	400	300	6	1	7.66	1895	7.86	1879
				3	6.81	1802	6.89	1788
				6	5.64	1725	5.78	1702
				9	4.34	1615	4.49	1592
				12	3.25	1365	3.48	1349
				15	2.01	1195	2.00	1178
Group #D1	500	700	6	1	18.23	2125	19.12	2105
				3	16.85	2045	17.32	2027
				6	14.87	1897	15.12	1879
				9	12.23	1766	12.45	1746
				12	9.99	1655	10.23	1642
				15	7.23	1549	7.44	1531
Group #D2	500	600	6	1	17.23	2105	17.68	2087
				3	15.61	1987	15.98	1968
				6	13.82	1825	14.21	1803
				9	10.87	1716	11.21	1712
				12	8.16	1561	8.32	1545
				15	6.55	1455	6.47	1437

Group #D3	500	500	6	1	16.89	1925	17.59	1898
				3	15.68	1836	16.12	1811
				6	14.73	1698	15.06	1672
				9	13.57	1588	14.11	1564
				12	11.82	1478	12.11	1453
				15	9.73	1394	10.05	1369
Group #D4	500	400	6	1	14.33	1911	15.10	1888
				3	12.75	1825	13.12	1805
				6	11.39	1737	11.76	1721
				9	9.25	1568	9.42	1548
				12	7.25	1423	7.42	1409
				15	5.31	1341	5.52	1325
Group #D5	500	300	6	1	7.36	1855	7.58	1834
				3	5.78	1768	5.91	1748
				6	4.68	1698	4.82	1672
				9	3.88	1522	4.06	1507
				12	3.27	1398	3.45	1371
				15	2.56	1276	2.74	1256

On a similar trend, the effect of EPS content on the compressive strength of the concrete showed a decreasing trend. EPS makes some portion of the concrete lighter, which is not as compact as the normal concrete, and consequently, the compressive strength will be lower. Although incorporating EPS particles helps to decrease the concrete's weight and grants it lower density, it also contributes to decreased concrete capacity to some extent, implying the concept of another positive outcome, but compromising the concrete's positive properties. As it is observed from the result, as the cement content in the mix increases, the density of concrete also increases. This is because the higher cement content means more cohesiveness of the mix. This does not allow many voids in the concrete mix but increases the density of the materials used extensively. On the other hand, the increment of the EPS beads content affected the density of concrete and reduced it significantly. Since EPS is lightweight, it also contributes to the porous structure of the concrete, thus reducing the amount of weight in the concrete. The above experimental results have underlined the significant role played by the mix proportions to create the right proportions of compressive strength and density. Therefore, it could be inferred from the results that the use of EPS-modified concrete can reduce the weight substantially, but more attention has to be paid to other factors concerning the concrete's properties; in this case, the 28-day compressive strength. The trade-offs presented in this study help practitioners understand the direction for using EPS in lightweight concrete while also pointing towards the empirical bird's-eye view of design.

3.3. Verification of the Developed ANN Model

The first step towards testing the overall performance of the proposed model was by employing the ANN model for the exclusive dataset that had been obtained from the experimental program. This dataset comprised 120 different mixes with concrete strength in the range 1.42 MPa to 18.23 MPa, and concrete density varied from 967 kg/m³ to 2087 kg/m³ as given in Table 2. Accordingly, the findings have indicated that it is possible to predict the concrete compressive strengths and densities precisely and accurately. A comparative analysis of the results obtained from the experimental data and the data obtained from the ANN method was carried out, and the findings are depicted in Figures 7 and 8.

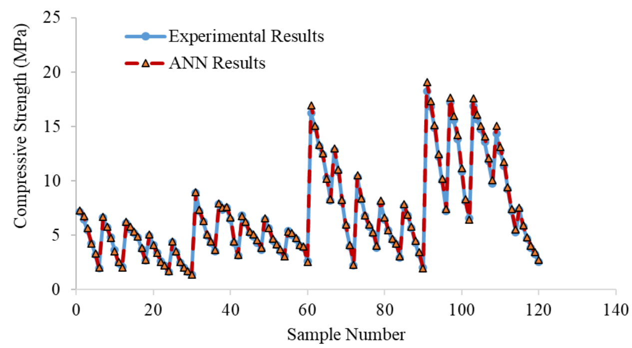

Fig.7 Experimental program and ANN predicted values of the compressive strength of concrete

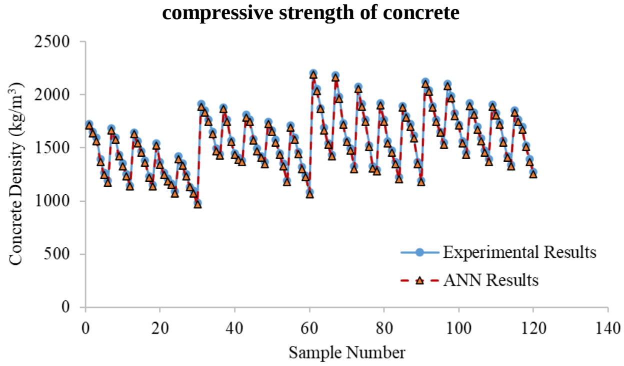

Fig. 8 Experimental program and ANN predicted values of the concrete density

As depicted in Figure 9, it is confirmed that the steepness of an ANN's prediction model of concrete's compressive strength and density was validated, and the maximum error committed was established to be 1.0 %. This covers testing that needs to be done, studying the data that is obtained, relooking at design mixes for concrete, and lastly arriving at the ideal mix. Furthermore, the model's determination coefficients were amazingly high; its value was equal to R = 0.99382 for training, R=0.96781 for validation, R=0.92772 for testing, and R=0.94938 for the overall dataset. Such high values of the correlation coefficient suggest that the predicted and experimental values are very close. Thus, it revealed that the margin of error was less than 1% (as shown in Figure 9) while using the proposed approach, indicating the model's high reliability and efficiency in determining the properties of EPS lightweight concrete. The inclusion of high particle quantities of Expanded Polystyrene (EPS) in the concrete decreases the total density of the concrete. Yet, it has adverse impacts on the mechanical characteristics and mainly the compressive strength. This is reduced due to the fact that EPS is extremely flexible and weak in comparison to traditional aggregates, and thus, there is less bonding to the cement matrix. Furthermore, excessive EPS will increase the void content and disturb the concrete's inner structure, reducing the loads it can bear and its durability.

Thus, this minor deviation to zero proves that ANN has great potential in assessing the properties of concrete, which, in a real sense, will help save ample time that would have been used in physical testing and, in turn, fast-track the design process in construction projects.

Besides correlation coefficients (R2) and Mean Squared Error (MSE), Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE) were also determined to obtain a comprehensible assessment of model precision. The ANN was able to get an RMSE value of around 0.22 to 0.32 MPa in predicting the compressive strength, i.e, an error margin of around 0.5% to 0.7%. In the density aspect, the RMSE was 7 to 10 kg/m 3, equating to error percentages between 0.44 and 0.63. These error percentages confirm the high accuracy and reliability of the model in predicting higher results than the conventional form of prediction.

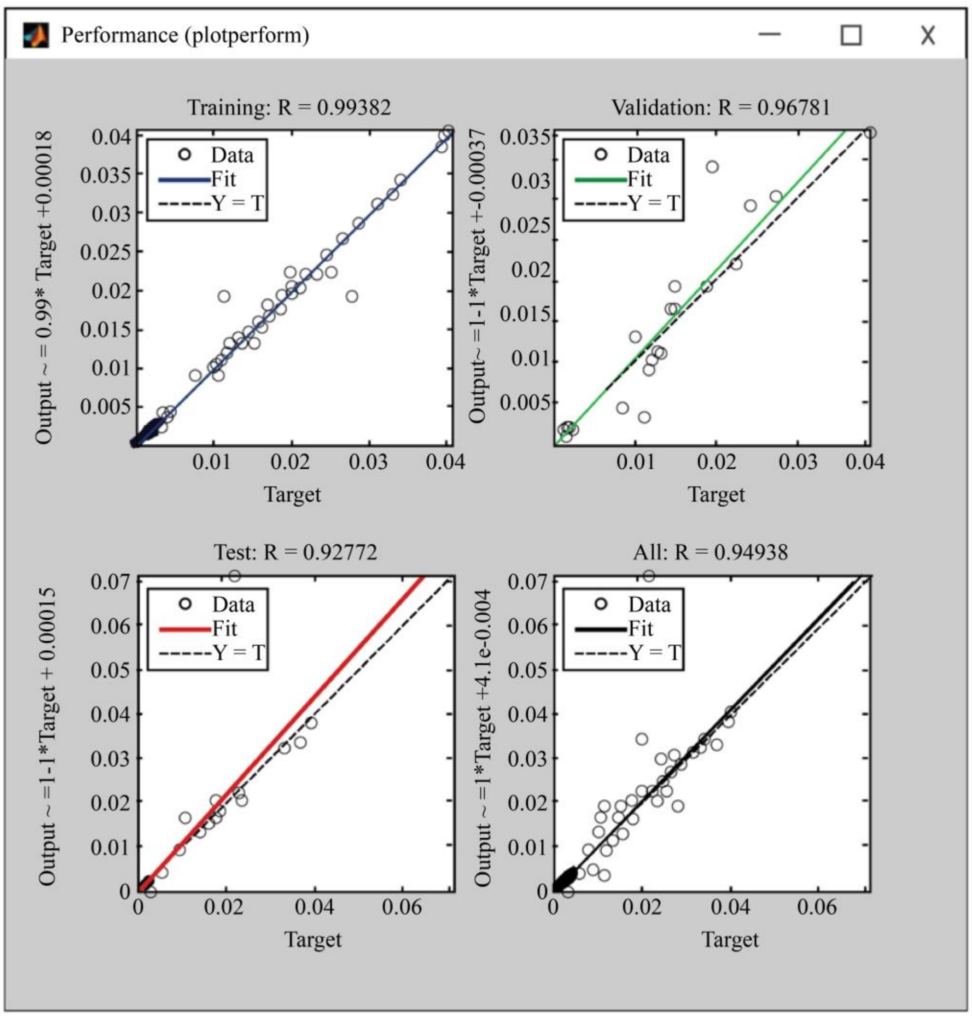

Fig. 9 Regression analysis results (R-Values for training, testing, validation, and all datasets)

4. Conclusion

The study, including the comprehensive experimental program, demonstrated the feasibility and performance properties of lightweight concrete containing EPS beads. The main conclusions of this investigation can be summarized as follows:

- Effect of Cement Content: Higher cement content substantially improves the densities and the compressive strength of the EPS lightweight concrete.
- Effect of EPS Content: An increase in the content of EPS beads always contributes to a decrease in both the compressive strength and the density of the concrete.
- Trade-offs: While using EPS in concrete, there is a trade-off between decreasing weight and compressive strength. This balance is important when looking at the workable uses of the two properties as value-added features.
- Use of ANN Models: ANN was used to estimate the compressive strength and density of the LWC by incorporating EPS beads. The accuracy of the coefficients of determination for the model was indeed amazingly high, and its value was R=0.94938 for the overall dataset. This shows that the ANN model is accurate and can be used to produce lightweight EPS concrete with desired properties; hence, there is little or no need for stressing experimental tests.
- Besides correlation coefficients (R2) and Mean Squared Error (MSE), Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE) were also determined to obtain a comprehensible assessment of model precision. The ANN was able to get an RMSE value of around 0.22 to 0.32 MPa in predicting the compressive strength, i.e, an error margin of around 0.5% to 0.7%. In the density aspect, the RMSE was 7 to 10 kg/m 3, equating to error percentages between 0.44 and 0.63. These error percentages confirm the high accuracy and reliability of the model in predicting higher results than the conventional form of prediction.
- More ANN studies need to include the effect of other factors that influence the EPS concrete properties, like the density and size of EPS beads, treatment method, and the effect of pozzolanic additives. Further research on the effective behaviour of concrete with EPS addition at various loads and/or analytical examinations of the concrete's influence on the environment and sustainability will thus advance the practice and increase the overall efficiency of construction materials with higher performance.
- Further research may be devoted to the investigation of the long-term durability and environmental adequacy of EPS lightweight concrete under ambient conditions, such as freeze-thaw tests and chemical impacts. Hybrid mixes with other sustainable aggregates/fibers might improve functionality and the replacement of EPS with other hybrid materials in terms of mechanical properties. Further refinement of ANN models to be constituted with additional factors, i.e., methods of curing and admixtures, etc., might enhance the accuracy of prediction and widen the scope of practical applicability.

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