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Mathematical Regression Models for Prediction of Durability Properties of Foamed Concrete with the Inclusion of Coir Fibre

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Abstract: A mathematical exploration using statistical techniques for the prediction of durability properties of foamed concrete with inclusion of coir fibre was performed for the foamed concrete data obtained from laboratory experimental work done in this research. The variable used in the prediction models was the fibre volume fractions. The multiple non-linear regression models yielded exceptional correlation coefficients for the prediction of water absorption, porosity, ultrasonic pulse velocity and depth of carbonation. The mathematical statistical procedures (regression models) that are proposed in this study provide tools of considerable value in the evaluation of durability properties of foamed concrete. The information derived from this procedure is valuable in filtering and refining design criteria and provisions related to foamed concrete with addition of coir fiber.

I. INTRODUCTION

At the present time, it has been broadly established that the construction industry around the world necessities building materials that are cost effective, durable, light, and simple to be utilized and naturally sustainable [1,2]. Furthermore, natural fibres have the aptitudes to achieve correspondingly as synthetic fibres [3]. Besides, this alternative does not need a high amount of energy and considered as decisive green products because it employs some agricultural wastes as construction materials [4].

Coir fibre has always been disposed as wastes instead of being exploited as construction materials [5]. The use of foamed concrete with coir fibre is able to reduce the weaknesses of foamed concrete which include low tensile strength, shrinkage problem, and serious crack propagation, especially in low densities foamed concrete [6,7]. Additionally, the inclusion of coir fibre is a practical way to improve the water absorption capacity, porosity, ultrasonic pulse velocity, bending performance as well as tensile cracking considering that foamed concrete is generally weak in tension compared to its capacity in compression [8,9,10].

In addition, the capability of fibres is dependent on the amount of fibres used in the mixture [11]. Higher percentage of fibre will lead to segregation and roughness of concrete and mortar [12]. However, fibres that are lengthy in the mix will create workability problems that can be discovered using the flow table test and during the pouring of the concrete into the mold [13,14].A considerable amount of studies has investigated foamed concrete involving two types of fibres, namely synthetic fibres and natural resources fibres (alternative option to make concrete naturally sustainable) [15,16].

On another note, the statistical procedures (regression models) that are proposed in the current research provide tools of considerable value in the evaluation of durability and mechanical properties of foamed concrete [17]. In addition, the information derived from this procedure is also valuable in filtering and refining design criteria and provisions. Meanwhile, statistical methods also have the added magnetism which states that they can be used to execute predictions quickly and simpler to contrivance in software once formfitting. Therefore, the prediction of foamed concrete properties has been an active area of research which has attracted numerous scholarly attentions. More importantly, numerous efforts have been taken to attain an appropriate mathematical model that is capable of predicting foamed concrete durability properties at various ages with satisfactory high precision. Hence this study attempts to carry out mathematical assessment using statistical techniques for the prediction of durability properties of foamed concrete with inclusion of coir fibre such as water absorption capacity, porosity, ultrasonic pulse velocity and depth of carbonation. The variable employed inthe prediction models was the fibre volume fractions.

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II. EXPERIMENTAL DATASET

Data for the present work has been taken from the experiments conducted to determine the water absorption capacity, porosity, ultrasonic pulse velocity and depth of carbonation of foamed concrete with the inclusion of different volume fraction of coir fibre. Three densities were considered in the experimental works which were 650 kg/m^3, 1050 kg/m^3 and 1450 kg/m^3. Coir fibre was used as additives in the present study at 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, and 0.6% by volume fraction of the total foamed concrete mixes. The proportion of mortar was cement, sand, and water which were represented by the ratio of 1:1.5:0.45. Water to cement ratio of 0:45 was utilized for all mixes considered in this research. Noraite PA-1 foaming agent which is protein-based was used for this experimental program due to its characteristics of good quality, potent and dense cell bubble structure. It is important to comprehend that foam is created using foam generator. The foaming generator furnished with a digital timer that can set the flow rate acts a medium that transforms the liquid chemical into stable foam. The foaming agents that produce stable foam output with the density around 65-75 g/liter. The current research utilized an uncrushed fine aggregate in mortar mixes as a constituent material, while the sand was sieved into 1.14mm size with a fineness modulus of 1.32 as well as a specific gravity of 2.72. The sieved fine aggregates were than stored in a tank and ready to be used for mixing. Figure 1 shows the fine sand grading curve used for the current research.

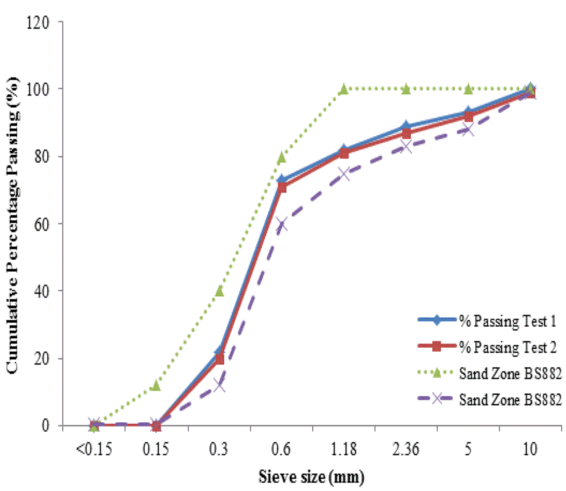

Fig. 1 Fine sand grading curve

III. EXPERIMENTAL PROCEDURE

Water absorption capacity test was performed according to BS 1881: Part 122 (1983) on cylinders with measurement 75mm ⌀ x 100mm. Porosity value for foamed concrete was assessed using the Vacuum Saturation Apparatus [18]. The testing technique for carbonation test was in accordance to BS 1881: Part 201 (1988). The carbonation tests were carried out at the exposure age of 70-days, 90-days, and 110-days. For ultrasonic pulse velocity test, it was executed using the Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT). A prism with the size of 100mm x 100mm x 500mm was built for this test carried out based on British Standards BS 1881 Part 203 (1986). Moreover, there is a PUNDIT together with the transmitter and receiver with the frequency of 54 kHz.

IV. RESULTS AND DISCUSSION

This section focuses on the development of statistical procedures (regression models) of durability properties of foamed concrete with different inclusion of volume fractions of coir fibre. The prediction models that were proposed provided the tools of substantial value in the assessment of durability properties of foamed concrete. Furthermore, the data derived from this process was also valuable in clarifying and filtering the design criteria and provisions in the context of lightweight foamed concrete. Other than that, the statistical approaches also have the added magnetism which can be used to accomplish faster predictions once formfitting.

A. Influence of coir fibre on water absorption of foamed concrete

Figure 2 demonstrates the relationship between fibre volume fraction and water absorption for all three densities. It very well may be observed that there is a non-direct reduction in water absorption of foamed concrete with higher amount of coir fibre volume division. This trend is consistent for all the densities examined. Table 1 shows the coefficients relating the coir fibre volume fraction to the water absorption. Regression analysis shows that the patterns that best depict the connection between coir fibre volume fraction and water absorption can be regarded as a polynomial function. The regression line with the R^2 value acquired for each of the three densities nearest to the value of 1 was taken as the regression line that best demonstrates the pattern of the water absorption data. This polynomial function inscribed in standard form is specified as Equation (1) shown below:

$$W_a = ax^2 + bx + c \quad (1)$$

where

W_a = water absorption of foamed concrete in %

a,b = the coefficient of the equation relating the coir fibre volume fraction to the water absorption found in Table 1

x = coir fibre volume fraction in %

c = the constant term of the equation relating the coir fibre volume fraction to the water absorption found in Table 1

Table 1. Coefficients relating the coir fibre volume fraction to the water absorption

Density	*a*	*b*	*c*	R^2
650	0.0714	-1.3000	23.386	0.9989
1050	0.0595	-1.1833	18.429	0.9965
1450	0.0940	-1.4917	13.729	0.9981

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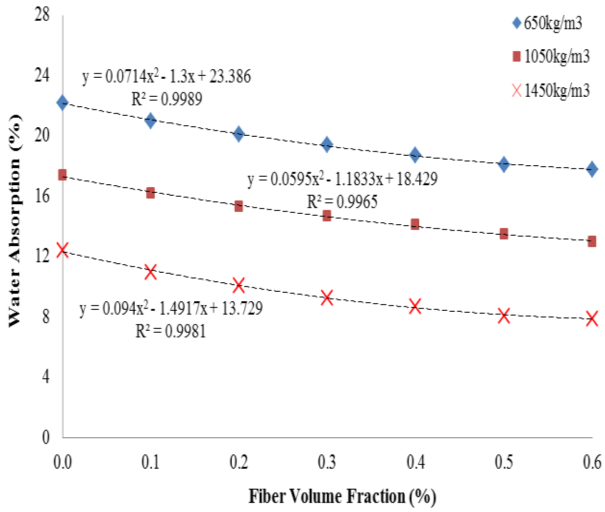

Fig. 2 Coir fibre volume fraction versus water absorption of foamed concrete

On another note, it should be pointed out that the internal structure of foamed concrete comprises of entrained air voids and capillary pores, thus indicating that not all of the pores and voids aggressively reacted to water absorbance [19].As can be seen from Figure 2, higher volume fraction of coir fibre in foamed concrete mix precludes water from penetrating into the cementitious matrix, thus owing to the small size of capillary pores, gel pores, and interlayer space. The development of pores and voids were diverse with various volume fractions of coir fibre [20]. Furthermore, the fundamental result of the hydration of Portland cement in foamed concrete was Calcium Silicate Hydrate with higher percentage of coir fibre that reduced the pore sizes, thus leading to low water absorption.

B. Influence of coir fibre on porosity of foamed concrete

Figure 3 reveals the connection between coir fibre volume fraction and porosity of all three densities evaluated in the current research. It can be seen that there is a linear decrease in porosity of foamed concrete due to higher coir fibre volume fraction. This trend is consistent for the entire densities scrutinized. The coefficient and exponent adopted for the purpose of explaining the porosity for the density of the concrete and coir fibre volume fraction is presented in Table 2. In all cases, a lower coir fibre volume fraction resulted in higher porosity of foamed concrete. Regression analysis displays that linear function describes the patterns that best depict the connection between coir fibre volume fraction and porosity. The regression line with the R^2 value nearly to the value of 1 was recorded as the regression line that shows the most suitable trend of porosity data. This linear function inscribed in standard form is indicated as Equation (2) shown as follows:

$$\Phi = ax + b \quad (2)$$

where

Φ = porosity of foamed concrete in %

a = the coefficient of the equation relating the coir fibre volume fraction to the porosity found in Table 2

x = coir fibre volume fraction in %

b = the constant term of the equation relating the coir fibre volume fraction to the porosity found in Table 2

Table. 2 Coefficients relating the coir fibre volume fraction to the porosity

Density	*a*	*b*	R^2
650	-1.0107	69.714	0.9906
1050	-1.1214	53.929	0.9914
1450	-1.1393	33.114	0.9974

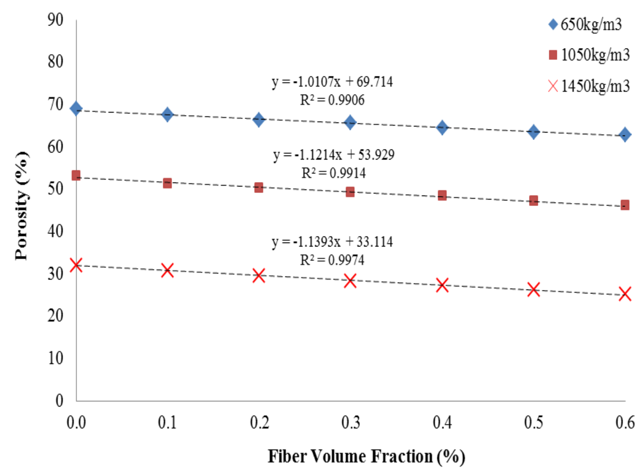

Fig. 3 Coir fibre volume fraction versus porosity of foamed concrete

Figure 3 shows that foamed concrete structures with higher volume of pores (lower densities) create more connectivity which enhances the flow-ability of fluid molecules. Moreover, it should be noted that situation usually takes place through the capillary effect in harden cement matrix which is driven by the force of osmosis force [21].

Hence, higher volume fraction of coir fibre plays a critical job in such a way. The diffusion of fluid molecules via the porous structure of foamed concrete will be ruined in unsystematic methods as though the coir fibre has no inclinations to absorb liquid particles.

C. Influence of coir fibre on ultrasonic pulse velocity of foamed concrete

Figure 4 illustrates the effect of coir fibre volume fraction on ultrasonic pulse velocity of foamed concrete. In this case, it can be clearly observed that there is a non-linear improvement of foamed concrete ultrasonic pulse velocity due to the increase of coir fibre volume fraction.

This inclination is revealed to be reliable and constant for 650 kg/m^3, 1050 kg/m^3, and 1450 kg/m^3 densities. Table 3 displays the coefficients relating the coir fibre volume fraction to the ultrasonic pulse velocity. Regression analysis demonstrates that the inclinations that best assign the connection between coir fibre volume fraction and ultrasonic pulse velocity can be considered as a polynomial function.

The regression line with the R^2 value obtained for all three densities nearest to the value of 1 was recorded as the regression line that best speaks the pattern of water absorption data.This polynomial function inscribed in standard form is specified as Equation (3) below:

$$UPV = ax^2 + bx + c \qquad (3)$$

where

- UPV = ultrasonic pulse velocity in m/s
- a,b = the coefficient of the equation relating the coir fibre volume fraction to the ultrasonic pulse velocity found in Table 3
- x = coir fibre volume fraction in %
- c = the constant term of the equation relating the coir fibre volume fraction to the ultrasonic pulse velocity found in Table 3

Table. 3 Coefficients relating the coir fibre volume fraction to the ultrasonic pulse velocity

Density	*a*	*b*	*c*	R^2
650	4.8214	2.1786	3021.1	0.9992
1050	3.5357	19.393	2283.3	0.9993
1450	4.8690	3.7976	1475.7	0.9963

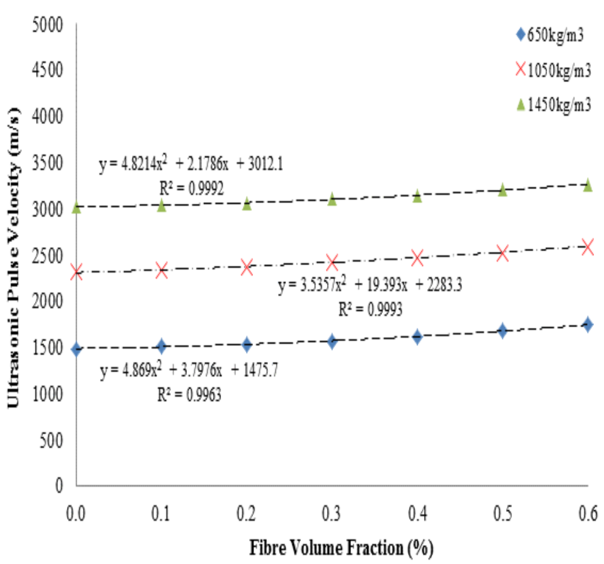

Fig. 4 Coir fibre volume fraction versus ultrasonic pulse velocity (UPV) of foamed concrete

Overall, it can be concluded that from Figure 4 that the addition of coir fibre in foamed concrete increases the ultrasonic pulse velocity (UPV) of the harden material, thus owing to high specific gravity of coir fibre itself. Therefore, foamed concrete control sample (no fibre) would have lesser UPV value compared to foamed concrete with the inclusion of coir fibre. The pulse wave passages faster via solid medium compared to liquid and gas mediums [22].

D. Influence of coir fibre on carbonation depth of foamed concrete

Figures 5-7 demonstrate the relationship between coir fibre volume fraction and carbonation depth of all three densities investigated in the current research. Moreover, there is a presence of a linear reduction in foamed concrete carbonation depth resulted by the increase of coir fibre volume fraction, which is consistent for all the densities examined. The coefficient and exponent utilized to define the carbonation depth based on the density of the foamed concrete as well as coir fibre volume fraction is presented in Table 4. In all cases, lower coir fibre volume fraction resulted in a greater carbonation depth of foamed concrete. The regression analysis represents that the patterns that best depict the connection between coir fibre volume division and carbonation profundity was described as a linear function. The regression line with the R^2 value nearly to the value of 1 was recorded as the regression line that best describes the trend of the porosity data. This linear function inscribed in standard form is indicated as Equation (4) shown below:

$$CD = ax + b \qquad (4)$$

where

- CD = carbonation depth of foamed concrete in %
- a = the coefficient of the equation relating the coir fibre volume fraction to the carbonation depth in Table 4
- x = coir fibre volume fraction in %
- b = the constant term of the equation relating the coir fibre volume fraction to the carbonation depth found in Table 4

Table. 4 Coefficients relating the coir fibre volume fraction to the carbonation depth

Density	Day	*a*	*b*	R^2
650	70	-0.9929	34.443	0.9881
	90	-1.0643	35.714	0.9832
	110	-1.1786	37.357	0.9827
1050	70	-0.9536	26.586	0.9909
	90	-0.9464	27.671	0.9926
	110	-0.8893	29.114	0.9904
1450	70	-0.6321	20.943	0.9912
	90	-0.6429	21.800	0.9929
	110	-0.7393	23.229	0.9915

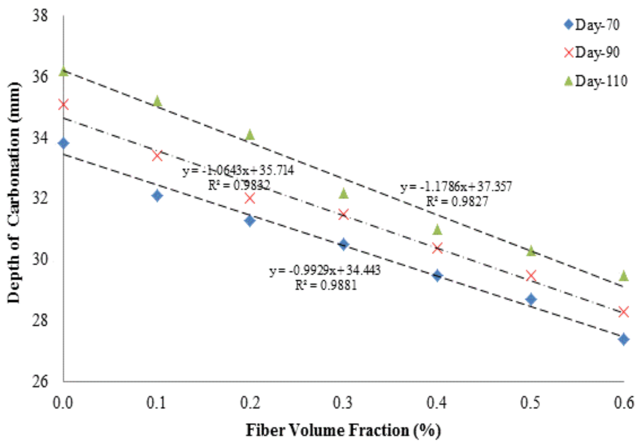

Fig. 5 Coir fibre volume fraction versus carbonation depth of 650 kg/m^3 density foamed concrete

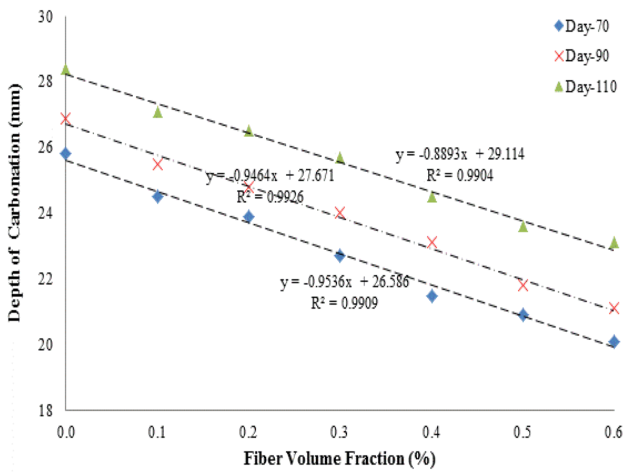

Fig. 6 Coir fibre volume fraction versus carbonation depth of 1050 kg/m^3 density foamed concrete

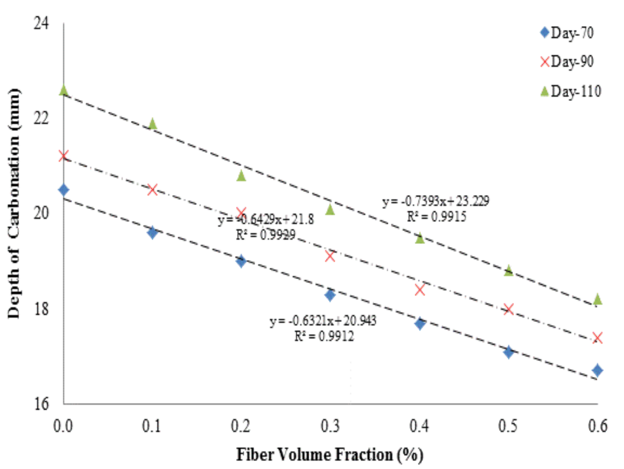

Fig. 7 Coir fibre volume fraction versus carbonation depth of 1450 kg/m^3 density foamed concrete

V. CONCLUSION

The statistical procedures (mathematical regression models) that were recommended in the research provide tools of considerable value in the evaluation of durability of foamed concrete with the inclusion of coir fibre. The information derived from this procedure is also valuable in filtering and refining design criteria and provisions. It should be pointed out that the statistical methods also have the added magnetism which states that they can be used to execute predictions quickly and simpler to contrivance in software once formfitting. From this mathematical regression models that have been proposed in this study, the accompanying main conclusions might be drawn on the impacts of coir fibre on the durability properties of foamed concrete:

1) The water absorption capacity of foamed concrete was slower at the beginning when it contained higher coir fibre volume fraction than the lower coir fibre volume fraction. Coir fibre absorbed water and then expanded amid blending. At that point towards the end of the drying procedure, the fibre lost its dampness and shrunk back to their unique dimension, thus leaving extremely fine voids around themselves. In addition, it was difficult for foamed concrete to absorb water when there are fine voids. In this way, it was expected normal that the absorption will diminish alongside the age. This situation revealed that coir fibre could anticipate brittleness and lose microstructure arrangement, which decreases the capacity to oppose undue loads.
2) Porosity of foamed concrete is abridged due to the increase of coir fibre for each density scrutinized. This transpires because of the reaction between the cement paste and coir fibre. Higher density foamed concrete stimuluses the decrement of permeable structure, while the coir fibre aids to bridge the matrix. The arrangement of pores for control foamed concrete without the integration of fibre was bigger compared to foamed concrete with the inclusion of coir fibre. Coir fibreas well aids in making an progressively uniform distribution of the air bubbles.
3) In terms of ultrasonic pulse velocity, it can be demonstrated that 650kg/m³ density has the most reduced outcome in contrast to 1050kg/m³ and 1450kg/m³. For those densities, 0.6% c expansion gave a brilliant ultrasonic pulse velocity (UPV) with the reading of 2592 m/s for 1050kg/m³ density and 3264 m/s for 1450kg/m³ density. This proves that the integration of coir fibre in foamed concrete base mix tends to expand the ultrasonic pulse velocity value of the cementitious material because of high explicit gravity of coir fibre.
4) The decrease of carbonation depth comes to pass when there is an increment of volume fraction of coir fibre and testing time, thus increasing the carbonation depth of foamed concrete. Therefore, it can be concluded from the outcomes that coir fibre with cement in the mix lead to more noteworthy protection from carbonation in contrast to plain mix.

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