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Use of Correlation and Regression Analyses as Statistical Tools in Green Concrete Research

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ABSTRACT

Correlation and regression in this paper were employed as analytical tools to study the degree of relationship as well as the nature and strength of the relationship between green concrete properties and percentage replacement of cement with civil engineering materials. Pearson product-moment method and Spearman's correlation coefficient were extensively used to show how correlation analysis can be practically applied in green concrete research. Least square regression line method for both linear relationship and non-linear relationship was also used to analyse the nature of the relationship between percentage replacement of cement with a pozzolana and green concrete properties like compressive strength and water absorption. The results of correlation analysis showed that Pearson product-moment is a better method for analysing green concrete properties when compared with Spearman's correlation coefficient, since Pearson's method takes cognizance of the actual data values unlike Spearman's use of data positions. The results of regression analysis also revealed that, for data whose trendline is polynomial in shape with the highest power of its assumed equation higher than that of quadratic equation, it is better to analyse such data using least square regression line method for linear relationship than least square regression line method for non-linear relationship. This is supported by the substantial difference in the predicted values of 40.79MPa and 36.20MPa for linear and non-linear relationship respectively for 35% replacement of cement with rice husk ash along with fly ash.

KEYWORDS: Compressive strength, correlation analysis, durability, green concrete, least square regression line, Pearson's product-moment, regression analysis, statistical tools.

1.0 INTRODUCTION

Concrete is a versatile construction material that can be manufactured using locally available materials like crushed stone, river sand and water. It is very popular when the fact is considered that around the world approximately twice as much concrete is used in construction than the total of all other building materials, such as, steel, plastic, wood, and aluminium. Its compressive strength is an important aspect in deciding its load carrying capacity [1]. Concrete according to Worrell as cited by [2] is the second most consumed entity after water and accounts for 5% of the world's total CO_2 emission as a result of the production of cement as one of its major ingredient and hence a threat to the environment, prompting the search for other materials that are environmental-friendly (green concrete).

Green concrete is defined as a concrete which uses waste material as at least one of its components, or its production process does not lead to environmental destruction, or it has high performance and life cycle sustainability [3]. Green concrete has nothing to do with colour. It is a concept of thinking environment into concrete considering every aspect from raw materials manufactured over mixture design to structural design, construction, and service life [4]. Green concrete is very cheap to produce because waste products are often used to make them; also charges for the disposal of waste are avoided as an added benefit [5]. The emergence of green concrete has to a large extent curb the environmental problem arising from unscientific and indiscriminate disposal of municipal solid waste, which is a real menace for the whole society. These wastes are increasing day by day due to increase in population, urbanisation and industrialisation. The characterisation of municipal solid waste according to Sharholy as cited by [6] shows that it contains about 55–65% of compostable material, 25–35% of dry/recyclable materials and 15-20% of inert material.

Efforts have been made in recent decades to develop “green” concretes containing industrial waste [7]. It is well known that in such green concretes cement has been partially replaced by industrial and/or agricultural byproducts such as fly ash, ground granulated blast furnace slag, metakaolin, rice husk ash, etc., which are considered as supplementary cementitious materials (SCMs). The replacement of cement by using SCMs not only decreases the landfills of waste materials and their associated environmental impacts, but also reduces the carbon footprint of concrete. In general, SCMs can be used to improve the mechanical properties of concrete, either in fresh or hardened mixtures [7].

According to [8], correlation measures the degree of linear association between two or more variables when a movement in one variable is associated with the movement in the other variable either in the same direction or the other direction. And regression analysis is the study of the nature and extent of association between two or more variables on the basis of the assumed relationship between them with a view to predict the value of one variable from the other. Correlation and Regression are two analyses that are based on multivariate distribution. Correlation is described as the analysis which lets us know the association or the absence of the relationship between two variables ‘x’ and ‘y’. On the other end, Regression analysis, predicts the value of the dependent variable based on the known value of the independent variable, assuming that average mathematical relationship between two or more variables exist [9]. People use regression on an intuitive level every day. In business, a well-dressed man is thought to be financially successful. A mother knows that more sugar in her children's diet results in higher energy levels. The ease of waking up in the morning often depends on how late you went to bed the night before. Quantitative regression adds precision by developing a mathematical formula that can be used for predictive purposes [10].

Correlation and regression as analytical tools use in statistics have been taught in so many institutions over the years especially in physical sciences and engineering fields; have been used in different works of life like industries and businesses; a lot of books and articles [11], [12], [13], [8]. have been written and published to make people understand correlation and regression analyses but have been seldomly applied in science and engineering academic research. This paper focuses on using linear correlation and linear and non-linear regression to analyse the results of the mechanical and durability properties of green concrete and to also show science and engineering researchers a possible way of applying these analytical tools in their future research in order to explain and predict the property been researched.

2.0 METHODS OF ANALYSIS

Correlation and regression are used as statistical tools to analyse results of mechanical (compressive strength) and durability (water absorption and sulphate attack on concrete) properties of green concrete and the analysed results discussed in statistical terms with relevance to civil engineering research on green concrete.

2.1 Correlation Analysis

Correlation shows the degree and direction to which two variables are related. It is a measure of the nature and strength of association existing between two variables. Correlation measures only linear relationship; it does not imply causality; and its coefficient is sensitive to extreme values.

Pearson's product-moment correlation and Spearman's correlation coefficient are the two types of correlation used for this analysis. Pearson's product-moment according to [13] is expressed as:

$$r = \frac{\sum \mathrm{XY}}{\sqrt{[(\sum \mathrm{X}^2)(\sum \mathrm{Y}^2)]}} \quad (1)$$

Where,

r = Pearson's coefficient of correlation

X = Value of the deviations of coordinate *x* from $\bar{x}$ (their mean value). That is, X = x-$\bar{x}$

Y = Value of the deviations of co-ordinate *y* from $\bar{y}$ (their mean value). That is, Y = y-$\bar{y}$

The values of Pearson's coefficient of correlation "r" lies between +1 and −1 and can be interpreted as follows:

Nature of Correlation: All positive (+) values of "r" means there is a "Direct correlation". While all negative (-) values of "r" means there is an "Inverse correlation".

Strength of Correlation: +1 and -1 indicates perfect direct and inverse correlation respectively; 0.70 to 0.99 and -0.70 to -0.99 indicates fairly direct and inverse correlation respectively; 0.10 to 0.69 and -0.10 to -0.69 indicates weak direct and inverse correlation respectively; 0 (zero) indicates that there is no linear correlation existing between the variables under consideration.

Spearman's correlation coefficient also called "Rank order correlation coefficient" is mathematically expressed as in "(2)" [8]:

$$r_s = 1 - \frac{6 \sum \mathrm{D}^2}{\mathrm{n}(\mathrm{n}^2 - 1)} \quad (2)$$

Where,

r_s = Spearman's correlation coefficient or rank order correlation coefficient

D = The difference between the positions or ranks of the two variables

n = The number of observation

The values of Spearman's correlation coefficient "r_s" also lies between +1 and −1 and can be interpreted in similar ways as Pearson's coefficient of correlation.

2.1.2 Regression Analysis

Regression analysis is the study of the nature and extent of association between two or more variables on the basis of the assumed relationship between them with a view to predict the value of one variable from the other [8]. Least square regression line method for linear and non linear relationship was used to obtain a_0 or θ_0, a_1 or θ_1, a_2, …, a_n in "(3)" to "(6)". Regression equation is always written in any of the following forms:

Simple or bivariate regression equation of y on x is

For linear relationship $$y = a_0 + a_1 x_1 + e \quad (3)$$

For non-linear relationship $$y = \theta_0 \exp(-\theta_1 x_1) + e \quad (4)$$

Multiple regression equation of y on x_1, x_2, …, x_n is

For linear relationship $$y = a_0 + a_1 x_1 + a_2 x_2 + \cdots + a_n x_n + e \quad (5)$$

For non-linear relationship $$y = \exp(-\theta_0 x_1)\,(1 - x_2)^{\theta_1} + e \quad (6)$$

Where,

y = The dependent variable

x = The independent variable

a_0 = The intercept of the regression line on the y-axis

a_1 = The slope

e = The error term

θ_0, θ_1 = Vectors of parameters

So according to [8], if there are n parts of observations (x_1, y_1), (x_2, y_2), … , (x_n, y_n), assuming a linear relationship,

$$y_i = a_0 + a_1 x_i + e_i$$

from which $$e_i = y_i - a_0 - a_1 x_i$$

If Q is taken as the summation of the error (e_i), then applying the least square principle,

$$Q = \sum_i^n e_i^2 = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)^2$$

Since there is no turning point for a straight line, differentiating Q partially with respect to a_0 and a_1 and equating the differential to zero gives:

$$\frac{\partial Q}{\partial a_0} = -2 \sum_i^n (y_i - a_0 - a_1 x_i) = 0$$

$$\sum y_i = na_0 + a_1 \sum x_i \quad (7)$$

$$\frac{\partial Q}{\partial a_1} = -2\sum_i^n (y_i - a_0 - a_1 x_i)x_i = 0$$

$$\sum y_i x_i = a_0 \sum x_i + a_1 \sum {x_i}^2 \quad (8)$$

"(7)" and "(8)" known as the "Normal Equations" are solved simultaneously to find the regression coefficient a_0 and a_1 of the regression line of *y* on *x*.

The non-linear equations used for regression analysis could be in exponential or logarithmic form depending on the data trend. According to [11], if there are n parts of observations (x_1, y_1), (x_2, y_2), … , (x_n, y_n), assuming a non-linear relationship,

$$y_i = \theta_0 \exp(-\theta_1 x_1) + e_i$$

from which $$e_i = y_i - \theta_0 \exp(-\theta_1 x_1)$$

If Q is taken as the summation of the error (e_i), then applying the least square principle,

$$Q = \sum_i^n e_i^2 = \sum_{i=1}^n (y_i - \theta_0 \exp(-\theta_1 x_1))^2 \quad (9)$$

At this point, different values of ϑ_0 and ϑ_1 are tried in "(9)" to check that, which gives the minimum or least square of the sum of errors (that is minimum $\sum_i^n e_i^2$). It is also important to know that non-linear equation for regression analysis is assumed based on the intuitive trendline that will be formed when the research results are plotted on a graph. Good knowledge of mathematics in terms of line shapes and their possible equations is indispensible in this regard. The possible line trends in green concrete research and their equation format are presented in Figures 1 and 2.

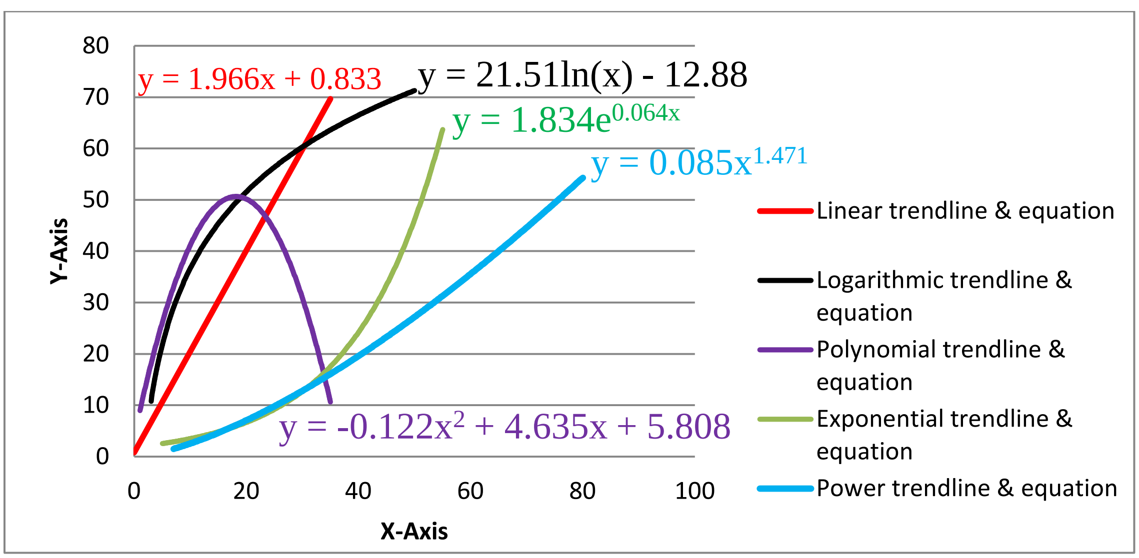

Fig. 1: Graph trendlines and their equation format 1

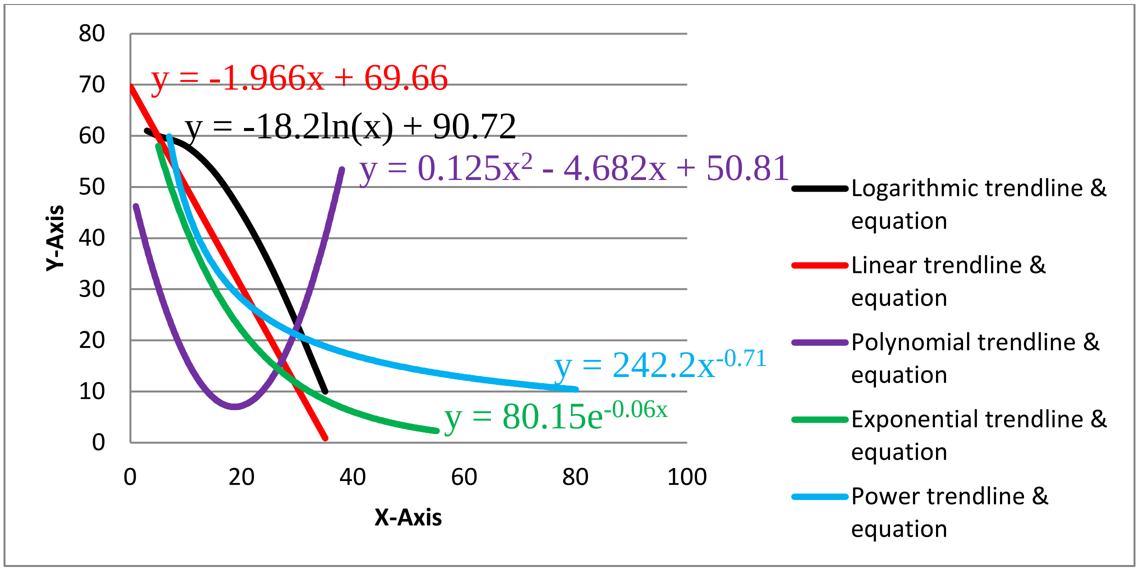

Fig. 2: Graph trendlines and their equation format 2

3.0 RESULTS, ANALYSIS AND DISCUSSION

This section is used to perform correlation and regression analyses of already researched results of compressive strength and durability properties of green concrete; and the result of each analysis discussed as it is applicable to civil engineering green concrete research.

3.1 Compressive Strength of Combined Rice Husk Ash and Fly ash Concrete

The result of compressive strength of green concrete made with 10% rice husk ash along with 10%, 20% and 30% fly ash as partial replacement of cement as researched by [14] is presented in Table 3.1a.

Table 3.1a: Compressive strength of combined fly ash and rice husk ash concrete

Mix Designation	Compressive strength (Mpa)		
	7 days	14 days	28 days
CM	24.6	32.4	40.1
R10FA10	26.5	36.2	42.3
R10FA20	29.3	41.5	44.6
R10FA30	25.5	33.1	38.4

Correlation Analysis

Using Pearson's product-moment formula,

$$r = \frac{\sum XY}{\sqrt{[(\sum X^2)(\sum Y^2)]}}$$

Let the mix designation be *x* and the compressive strength at 28 days be *y*.

Table 3.1b gives the detail values of the parameters in the equation

Table 3.1b: Detail values of parameters

	x	y	X=$x-\bar{x}$	Y=$y-\bar{y}$	XY	X^2	Y^2
	0	40.1	-15	-1.25	18.75	225	1.5625
	10	42.3	-5	0.95	-4.75	25	0.9025
	20	44.6	5	3.25	16.25	25	10.5625
	30	38.4	15	-2.95	-44.25	225	8.7025
$\sum =$	60	165.4			-14	500	21.73

$$\bar{x} = \frac{\sum x}{n} = \frac{60}{4} = 15$$

$$\bar{y} = \frac{\sum y}{n} = \frac{165.4}{4} = 41.35$$

Hence,

$$r = \frac{-14}{\sqrt{[(500)(21.73)]}} = -0.13$$

Discussion: The value of Pearson's correlation coefficient "r" showed a very weak inverse relationship between the green concrete compressive strength and the percentage replacement of cement with rice husk ash along with fly ash. This means that the compressive strength of the green concrete will drastically reduce with increase in percentage replacement of cement with rice husk ash along with flyash.

Using Spearman's correlation coefficient formula,

$$r_s = 1 - \frac{6\sum \mathrm{D}^2}{\mathrm{n}(\mathrm{n}^2-1)}$$

Let the mix designation be *x* and the compressive strength at 28 days be *y*.

Table 3.1c gives the detail values of the parameters in the equation

Table 3.1c: Detail values of parameters

x	*y*	Rank *x*	Rank *y*	|D|=|*x*-*y*|	$\|D\|^2$
0	40.1	1	2	1	1
10	42.3	2	3	1	1
20	44.6	3	4	1	1
30	38.4	4	1	3	9
				$\sum =$	12

Hence,

$$r_s = 1 - \frac{6 \text{ x } 12}{4(4^2 - 1)} = -0.20$$

Discussion: The value of Spearman's correlation coefficient "r_s" also showed a very weak inverse relationship between the green concrete compressive strength and the percentage replacement of cement with rice husk ash along with fly ash. This means that there won't be any satisfaction in increasing the percentage replacement of cement with rice husk ash along with fly ash beyond the 30% as it will result into substantial reduction in the compressive strength of the concrete.

Regression Analysis

Using least square regression line method for linear relationship,

$$y = a_0 + a_1 x$$

Let the mix designation be *x* and the compressive strength at 28 days be *y*.

Table 3.1d gives the detail values of the parameters in the equation

Table 3.1d: Detail values of parameters

	x	*y*	x^2	y^2	*yx*
	0	40.1	0	1608.01	0
	10	42.3	100	1789.29	423
	20	44.6	400	1989.16	892
	30	38.4	900	1474.56	1152
$\sum =$	60	165.4	1400	6861.02	2467

Using the normal equations to find a_0 and a_1,

$$\sum y = na_0 + a_1 \sum x$$

$$165.4 = 4a_0 + 60a_1 \qquad \text{(A)}$$

$$\sum yx = a_0 \sum x + a_1 \sum x^2$$
$$2467 = 60a_0 + 1400a_1 \qquad \text{(B)}$$

Solving equations A and B simultaneously, a_0 = 41.77 and a_1 = -0.028

Hence, the equation of the regression line of compressive strength (*y*) on mix designation (*x*) is

$$y = 41.77 - 0.028x$$

Discussion: The linear regression analysis revealed that the compressive strength of the green concrete will decrease if more rice husk ash along with fly ash is used to replace cement. This analysis also makes it possible to predict the compressive strength of the green concrete at 28 days curing duration for any percentage replacement of cement with rice husk ash along with flyash, as it yielded 40.79MPa at 35% replacement of cement with rice husk ash along with fly ash.

Using least square regression line method for non-linear relationship, a trial plot of the data on a graph will show that the trend line is quadratic (like the polynomial trendline in Figure 3). So

$$y = -\theta_0 x^2 + \theta_1 x + \theta_2$$

Let the mix designation be *x* and the compressive strength at 28 days be *y*.

Table 3.1e gives the detail values of the parameters in the equation

Table 3.1e: Detail values of parameters

Assume θ_0, θ_1 and θ_2 = 0.025, 0.60 and 40.0 respectively as trial values				
x	*y* (from Experiment)	$y_c = -\theta_0 x^2 + \theta_1 x + \theta_2$	$e = y - y_c$	e^2
0	40.1	40.0	0.1	0.01
10	42.3	43.5	-1.2	1.44
20	44.6	42	2.6	6.76
30	38.4	35.5	2.9	8.41
			$\sum =$	16.62

Table 3.1f: Detail values of parameters

Assume θ_0, θ_1 and θ_2 = 0.020, 0.60 and 39.7 respectively as trial values				
x	y (from Experiment)	$y_c = -\theta_0 x^2 + \theta_1 x + \theta_2$	$e = y - y_c$	e^2
0	40.1	39.7	0.4	0.16
10	42.3	43.7	-1.4	1.96
20	44.6	43.7	0.9	0.81
30	38.4	39.7	-1.3	1.69
			$\sum =$	4.62

Since Table 3.1f gives the least of the sum of square of error (that is $\sum e^2 = 4.62$), θ_0 = 0.020, θ_1 = 0.60 and θ_2 = 39.7.

Hence, the equation of the regression line of compressive strength (*y*) on mix designation (*x*) is

$$y = -0.020x^2 + 0.60x + 39.7$$

Discussion: The non-linear regression analysis also revealed that the compressive strength of the green concrete will decrease if more rice husk ash along with fly ash is used to replace cement. It was confirmed by using the equation to predict the green concrete compressive strength for 35% replacement of cement with rice husk ash along with fly ash which yielded 36.20MPa. It is also noted that least square regression line method for linear relationship can be used for all non-linear relationship with polynomial and power trendline since the powers only apply to the independent variable *x* and not the θs.

3.2 Water Absorption of Combined Fly ash and Alccofine Concrete

Table 3.2a presents [15] result of water absorption of green concrete produced using 30% fly ash with 0%, 4%, 8% and 12% alccofine 1203 to replace cement.

Table 3.2a: Water absorption of combined fly ash and alccofine concrete

Mix	Oven dried weight (kg)	Weight of specimen (kg)	% Water absorption
CM	24.6	8.9	0.56
R10FA10	26.5	8.581	0.256
R10FA20	8.551	8.752	0.244
R10FA30	9	8.829	0.23

Correlation Analysis

Using Pearson's product-moment formula,

$$r = \frac{\sum \mathrm{XY}}{\sqrt{[(\sum \mathrm{X}^2)(\sum \mathrm{Y}^2)]}}$$

Let the mix be *x* and the water absorption be *y*.

Table 3.3b gives the detail values of the parameters in the equation

Table 3.2b: Detail values of parameters

	x	y	X=$x-\bar{x}$	Y=$y-\bar{y}$	XY	X^2	Y^2
	0	0.56	–15	0.24	-3.6	225	0.058
	10	0.256	–5	–0.064	0.32	25	0.0041
	20	0.244	5	–0.076	–0.38	25	0.0058
	30	0.23	15	–0.09	–1.35	225	0.0081
$\sum =$	60	1.29			-5.01	500	0.076

$$\bar{x} = \frac{\sum x}{n} = \frac{60}{4} = 15$$

$$\bar{y} = \frac{\sum y}{n} = \frac{1.29}{4} = 0.32$$

Hence,

$$r = \frac{-5.01}{\sqrt{(500)(0.076)}} = -0.81$$

Discussion: The value of Pearson's correlation coefficient "r" revealed a fairly inverse relationship between the green concrete water absorpton and the percentage replacement of cement with combined fly ash and alccofine. This means that the water absorption of the green concrete will decrease with increase in percentage replacement of cement with combined fly ash and alccofine.

Regression Analysis

Using least square regression line method for non-linear relationship, a trial plot of the data on a graph will show that the trend line is exponential (like the exponential trendline in Figure 4). So

$$y = \theta_0 e^{-\theta_1 x}$$

Let the mix be *x* and the water absorption be *y*.

Table 3.3c gives the detail values of the parameters in the equation

Table 3.2c: Detail values of parameters

Assume θ_0, and θ_1 = 0.47 and 0.02 respectively as trial values				
x	*y* (from Experiment)	$y_c = \theta_0 e^{-\theta_1 x}$	$e = y - y_c$	e^2
0	0.56	0.47	0.09	0.0081
10	0.256	0.385	-0.129	0.0166
20	0.244	0.315	-0.071	0.00504
30	0.23	0.258	-0.028	0.000784
			$\sum =$	0.0305

Table 3.2d: Detail values of parameters

Assume θ_0, and θ_1 = 0.44 and 0.02 respectively as trial values				
x	*y* (from Experiment)	$y_c = \theta_0 e^{-\theta_1 x}$	$e = y - y_c$	e^2
0	0.56	0.44	0.12	0.0144
10	0.256	0.36	-0.104	0.0108
20	0.244	0.295	-0.051	0.0026
30	0.23	0.241	-0.011	0.000121
			$\sum =$	0.0279

Since Table 3.2d gives the least of the sum of square of error, θ_0 = 0.44 and θ_1 = 0.02.

Hence, the equation of the regression line of water absorption (*y*) on mix (*x*) is

$$y = 0.44e^{-0.02x}$$

Discussion: The non-linear regression analysis has revealed that the water absorption of the green concrete will decrease if more combined fly ash and alccofine is used to replace cement. For instance, using the regression equation to predict the water absorption of the green concrete when cement is replaced with 35% combined fly ash and alccofine yields 0.218 % water absorption.

CONCLUSION

Correlation and regression were used as statistical tools to analyse the mechanical and durability properties of green concrete. The use of these analytical tools showed that the degree of relationship that exists between a green concrete property (for example compressive strength or water absorption or resistance to sulphate attack) and percentage replacement of cement with a civil engineering material can be established using correlation; the nature and extent of the relationship can be known using regression; and the green concrete property analysed using regression can be predicted with the regression equation.

The results of regression analysis in section 3.1 has also shown that, for data whose trendline is polynomial in shape with the highest power of its assumed equation more than two (that is higher than quadratic equation), it is better to analyse such data using least square regression line method for linear relationship than least square regression line method for non-linear relationship as section 3.1 produced predicted values of 40.79MPa and 36.20MPa for linear and non-linear relationship respectively for 35% replacement of cement with rice husk ash along with fly ash.

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