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INVESTIGATION THE EFFECTS OF GREEN MORTAR PARAMETERS USING ANALYTICAL METHODS

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The various green mortar mixes have been used in this study using various percentages of waste glass powder (WGP), steel slag (SG) and Micro-silica fume(SF). The different properties of flow, density, ultrasonic pulse velocity (UPV), compressive and flexural strengths have been tested for such green mortar in the first phase of experimental work. The second phase deals with the regression analysis of such properties. Whereas, the analysis of the results have also been using the integrated AHP and TOPSIS methods for selection the best performance of the green mortar due to the ecological effects of such materials. The results showed that the use of 70%OPC+8%WGP+12%SG+10% SF indicated as the best performance in term of ecological impact compared with other mortar mixes. Also, the regression analysis using the integrated AHP and TOPSIS methods gives an effective strategy for the selection of the best mortar mix.

Key words: green mortar, environmental effects, regression analysis, AHP, TOPSIS

INTRODUCTION

Cement considers as most produced materials in the world. The annual global cement production ranges to 4.15 billion tons in 2016, and is expected to increase to 4.25 billion tons per year in 2030 (1). The production of this material needs the use of a huge amount of raw materials, energy and fossil fuels in addition to air and water (2,3,4). The pollutants generated and non-renewable resources consumed during cement industry make cement material has a negative impact on the environment (4). Although this industry causes the formation of wastewater, solid waste, and noise, the main environmental issues are associated with air emissions and energy consumption. The high amounts of the carbon dioxide (CO_2), nitrogen oxides (NO, NO_2, N_2O), sulfur oxides (SO2, SO3) and dust emissions in addition to the other air pollutants are released from cement manufacturing (5,6.7,8). Approximately 8% of global carbon dioxide (CO_2) emission is liberated from cement industry (8). Moreover, the production of one ton of cement releases 360 pounds of dust (9),requires about 1.597 metric ton of raw materials (9,10) and consumes a high amounts of electricity and thermal energy. Another various industrial processes (silicon metal, ferrosilicon and steel) also have a significant role on the environment impact. The accumulation of solid wastes generated as a byproduct of these industry is one of the reasons which lead to deteriorate the environment. In 2016, the global crude steel, silicon and ferrosilicon production has estimated at 1630, 2.7 and 6.4 million tons respectively (11). Production of one ton of the steel, silicon and ferrosilicon generates a high amount of solid waste like slag and silica fume dust respectively (12). Besides the accumulation of the non-biodegradable solid waste like waste glass in the landfills is the one of phenomena which has negative impact on the environment. For reducing this environmental impact, reducing of raw materials and energy consumption during cement production, producing sustainable building material, saving in cement and recycling of waste products, many materials were blended with cement to make green building materials (13-16). Waste glass powder (WGP), Steel slag (SG) and Silica fume (SF) are non-biodegradable materials and available as waste materials (17-19). Utilization these materials with cement can improve mortar flowability, early and long term strength and long term durability (20-22). Physical properties and chemical composition of these materials have a significant role on the properties of concrete. Many previous studies (23-26) have concluded that the chemical composition and the particle size of WGP have governed its pozzolanic activity, smaller particles decrease alkali silica reaction and give higher strength.

Several researchers (22-35) have focused on the use of SG with cement to improve the density ,durability and strength of concrete at later ages. Many researchers (28-32) have studied the properties of mortar or/and concrete prepared from blended cement with supplementary cementitious materials (SCMs).Silica fume is the one of SCMs which can contribute to improve the mechanical properties of mortar and concrete at identical water-binder ratio (W/b) and replacement level (33-35).

Several researchers have worked to improve accurate building material properties and predict new models.

Multiple regression analysis is the one of statistical techniques which have been utilized to analysis properties of concrete and mortar, predict the good relationship between concrete or mortar properties and produce generalized results for new concrete or mortar before test. Therefore, the objectives of this research are to study the

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multiple regression analysis for green mortar properties and to selecting the best green mortar based on its impact on the environment.

MATERIALS AND MIX PROPORTIONS

Materials

The physical and mechanical properties of Ordinary Portland Cement(OPC), waste glass powder (WGP) steel slag (SG) and silica fume (SF) are given in Table 1. The properties of superplasticizer are shown in Table 2. Tap water was utilized in all mixes. The sand used for preparing green mixes was prepared according to ASTM C778 (36). Superplasticizer was procured from Specialties construction chemicals factory, Jahra, Kuwait. Its commercial name is KUT PLAST PCE 600. It was used to enhance the workability of mixes.

Mix proportions

In this study, nineteen (19) mixes were prepared to produce green mortars, binder/sand ratio was 1:2.75, water + superplasticizer / binder ratio (W+SP/B) was 0.39, the mix proportions of these mixes are listed in Table 3.

METHODOLOGY

Experimental method

Flow test was conducted for each mix according to ASTM C1437 (37). Dry density test was conducted for 70.7×70.7×70.7mm specimens at 28 day according to ASTM C642 (38). Ultrasonic pulse velocity (UPV) was performed through 70.7×70.7×70.7 mm specimens at 28 day as per to ASTM C597 (39) after thirty minutes of taking them out of water. The compressive and flexural strength tests were applied on 50×50×50 mm cubes and 40×40×160 mm

Table 1: Physical properties and Chemical compositions of the OPC, WGP, SG and SF

Description	OPC*	WGP**	SG**	SF**
Physical properties				
Specific gravity, gm/cm^3	3.15	2.315	4.994	1.98
Blaine's fineness, cm^2/gm	3560	4094	8028	-
Chemical composition (% wt.)				
Ferric oxide, Fe_2O_3 %	3.44	1.168	95.430	0.795
Calcium oxide, CaO %	61.46	11.940	0.646	1.436
Silicon dioxide, SiO_2 %	19.53	72.71	4.027	93.29
Potassium oxide, SO_3 %	2.25	0.323	0.837	0.851
Alkalies (0.658 K_2O + Na_2O) %	0.58	8.906	1.078	0.875
Manganese oxide, MnO %	-	0.014	0.496	0.043
Magnesium oxide, MgO %	3.82	1.480	0.141	0.137
Aluminum oxide, Al_2O_3 %	4.92	1.487	0.523	0.264
Loss of ignition, %	3.11	-	-	-
C_3S %	57.39	-	-	-
C_2S %	13.53	-	-	-
C_3A %	7.20	-	-	-
C_4AF %	10.46	-	-	-
*Provided by the manufacturer of cement-Delta Cement Company-Sulaymania-Iraq				
**Tested by the authors				

Table 2: Properties of superplasticizer

Typical characteristics				
Specific gravity	Setting time	Air entrainment	Chloride content	Calcium chloride Content
1.06 - 1.08 @ 20ºC	No retardation at normal dosage	<1% additional air is entrained	Nil to Bs 5075	Nil

prisms at different ages (7 and 28 days) by using ASTM C109 (40) and ASTM C348 (41) respectively.

Collection of the estimated data resulting from industrials processes and computing of the amount of the resources consumed and pollutants generated from cement industry

The estimated data of solid waste accumulated, the resources consumed and the emissions resulted from cement industry

Based on the evaluated data in 2016, the global cement production was reached to 4150 million tons (1). Raw materials such as Limestone, clay, Sand and iron ore are the main requirements for cement production and are consumed in the large quantity (42). According to previous studies (9,10), the production of the one ton of cement requires about 1597 kg of raw materials. Therefor the global amount of raw materials consumed in 2016 were evaluated at 6628 million tons in this study. During cement manufacturing, the electricity and thermal energy are used in sufficient level. The thermal energy is used during cement processing while electricity energy is used for grinding of raw materials of cement and clinker (43,44). The global amount of electricity energy and thermal energy consumed in 2016 was estimated at 91KWh and 3400 mega joules per one ton of cement and clinker produced respectively and the clinker to cement ratio was estimated at 0.66 (1). Furthermore, the global amount of thermal energy consumed per one ton of cement produced was calculated at 2244 mega joules in this research. Cement industry not only consumes non-renewable resources like raw materials, thermal energy and electricity energy but also releases air pollutants like CO_2 and dust which have a negative impact on the environment and human health (79). About fifty percent (50%) of Carbon dioxide (CO_2) released during cement industry is resulted from calcination process of limestone ($CaCO_3$) and another fifty percent (50%) is resulted from fuel combustion in cement kilns (35). In 2016, the global amount of carbon dioxide (CO_2) emitted per one tone of cement produced was reached to 530 kg (1). Thus, the total amount of the global carbon dioxide (CO_2) emitted from the total amount of cement produced in the same year was estimated at 2200 million ton. In addition, the global amount of dust emitted during cement industry was also estimated at 676 million ton in this research based on the production of the one ton of cement releases approximately 163 Kg of dust (9). Table 4. illustrated the summary of available data for production of one ton of cement in 2016.

On the other hand, the global amount of the crude steel,

Table 3: Mix proportions of green mortar

Cement mixes (%)	OP (Kg/m^3)	WGP (Kg/m^3)	SG (Kg/m^3)	Sand (Kg/m^3)	SP. (L/m^3)	W+SP./B
100%OPC	565	0	0	1554	2	0.39
90%OPC+10%WGP	506	56	0	1546	2	0.39
85%OPC+15%WGP	476	84	0	1540	2	0.39
80%OPC+20%WGP	446	112	0	1535	1.7	0.39
90%OPC+10%SG	512	0	57	1565	2	0.39
85%OPC+15%SG	485	0	86	1570	2	0.39
80%OPC+20%SG	458	0	115	1576	2	0.39
94%OPC+6%SF	528	0	0	1546	2	0.39
92%OPC+8%SF	515	0	0	1540	2	0.39
90%OPC+10%SF	503	0	0	1537	2	0.39
80%OPC+8%WGP+12%SG	454	45	68	1559	2	0.39
80%OPC+10%WGP+10%SG	452	45	68	1554	2	0.39
80%OPC+5%WGP+15%SG	455	29	85	1565	2	0.39
78%OPC+10%WGP+12%SG	441	57	68	1557	2	0.39
75%OPC+12.5%WGP+12.5%SG	423	71	71	1554	2	0.39
75%OPC+10%WGP+15%SG	425	57	85	1559	2	0.39
74%OPC+8%WGP+12%SG+6%SF	417	45	68	1551	2	0.39
72%OPC+8%WGP+12%SG+8%SF	405	45	67	1546	2	0.39
70%OPC+8%WGP+12%SG+10%SF	393	45	67	1543	2	0.39

Table 4: Summary of the evaluated data during the global cement production in 2016 (1, 9,43-44)

Production one ton of cement	Raw materials consumption (Kg)	Electricity energy consumption (KWh)	Thermal energy consumption (Mj)	CO_2 emission (kg)	Dust emission (Kg)
	1597	91	2244	530	163

silicon and ferrosilicon production had evaluated at 1630, 2.7 and 6.4 million tons respectively in 2016 (11). Approximately, 400 kg of steel slag, silica fume has produced as a byproduct per one ton of steel, silicone and ferrosilicon manufactured respectively (12) Therefore, the total amount of steel slag, silica fume in 2016 was estimated at 652, 3.64 million tons in this study. In addition, the global amount of the municipal solid waste was estimated to 2017 million tons in the same year (48). And the waste glass powder had formed about 5% of the municipal solid waste (48).

The calculation of the amount of the resources consumed and air contaminants resulting from cement used in the preparation of the traditional mortar and non-reinforced green mortars

The quantity of non-renewable resources (raw materials, electricity and thermal energy) consumed and air pollutants (carbon dioxide and dust) emitted during cement industry was calculated in this study. The calculation was based on the amount of cement used for preparation of the traditional mortar and non-reinforced green mortars. The data in Table 5 was used in the calculation of the total quantities of raw materials, electricity energy, thermal energy, CO_2 and dust resulting from cement used in the conventional mortar and non-reinforced green mortar. In order to reduce the amount of cement used in the preparation of mortars, the solid waste (waste glass, steel slag and silica fume) was used as partial replacement of cement as listed Table 5. This table illustrated the amount of resources consumed and air pollutants generated from cement used to prepare the conventional mortar and non-reinforced green mortar.

RESULTS AND DISCUSSION

The results for green mortar mixes are shown in Table 6. The results showed that the acceptable ranges of strengths and other properties can also be obtained using 30% replacements of cement.

Regression analysis

For analysis of green mortar data, Multivariable linear regression analysis (MLRA) was employed. The purpose of this analysis is to explain the relationship between one dependent variable and two or more independent variables. The general MLRA equation was shown below:

$$Y=C+b_1X_a+b_2X_b+\cdots+b_nX_n\pm e$$

Table 5: Quantity of cement and solid waste used for preparing mortars

Number of mix	Cement amount (Kg/m^3)	Resource consumed and Air pollutants emitted per one kilogram of cement*					Amount of Solid waste replaced by cement		
		Raw materials (Kg/m^3)	Electricity energy (KWh)	Thermal energy (Mj)	CO_2 (Kg/m^3)	Dust (Kg/m^3)	Waste glass (Kg/m^3)	Steel slag (Kg/m^3)	Silica fume (Kg/m^3)
1	565	902	51	1268	299	92	0	0	0
2	506	808	46	1135	268	82	56	0	0
3	476	760	43	1068	252	78	84	0	0
4	446	712	41	1001	236	73	112	0	0
5	512	818	47	1149	271	83	0	57	0
6	485	775	44	1088	257	79	0	86	0
7	458	731	42	1028	243	75	0	115	0
8	528	843	48	1185	280	86	0	0	34
9	515	822	47	1156	273	84	0	0	45
10	503	803	46	1129	267	82	0	0	56
11	454	725	41	1019	241	74	45	68	0
12	452	722	41	1014	240	74	45	68	0
13	455	727	41	1021	241	74	29	85	0
14	441	704	40	990	234	72	57	68	0
15	423	676	38	949	224	69	71	71	0
16	425	679	39	954	225	69	57	85	0
17	417	666	38	936	221	68	45	68	34
18	405	647	37	909	215	66	45	67	45
19	393	628	36	882	208	64	45	67	56

*Calculated according to same references listed in Table 4 (1,9, 43-44)

Table 6: Green mortar test results

Mix No.	Cement mixes (%)	Flow (%)	Compressive strength (MPa)	Flexural strength (MPa)	UPV. (Km/sec)	Dry density (Kg/m^3)
			28 day	28 day	28 day	28 day
1	100%OPC	113	40.331	7.823	4.521	2266
2	90%OPC+10%WGP	113	31.722	6.782	4.046	2210
3	85%OPC+15%WGP	115	40.017	7.800	4.402	2256
4	80%OPC+20%WGP	109	36.340	7.497	4.287	2250
5	90%OPC+10%SG	113	31.080	6.691	4.001	2212
6	85%OPC+15%SG	110	33.016	7.142	4.131	2242
7	80%OPC+20%SG	105	26.610	6.209	3.527	2165
8	94%OPC+6%SF	105	42.836	7.482	4.556	2270
9	92%OPC+8%SF	100	43.394	7.563	4.582	2283
10	90%OPC+10%SF	82	48.866	8.032	4.713	2369
11	80%OPC+8%WGP+12%SG	108	31.896	6.679	4.024	2220
12	80%OPC+10%WGP+10%SG	115	33.927	7.380	4.356	2248
13	80%OPC+5%WGP+15%SG	105	32.344	6.977	4.207	2229
14	78%OPC+10%WGP+12%SG	110	31.908	6.782	4.092	2222
15	75%OPC+12.5%WGP+12.5%SG	113	32.569	7.146	4.227	2235
16	75%OPC+10%WGP+15%SG	109	30.331	6.094	4.032	2206
17	74%OPC+8%WGP+12%SG+6%SF	113	29.323	6.502	3.901	2197
18	72%OPC+8%WGP+12%SG+8%SF	110	30.088	6.821	4.021	2210
19	70%OPC+8%WGP+12%SG+10%SF	108	32.068	7.321	4.107	2225

Where, Y is dependent variable; C is constant; b_1, b_2 and b_n are slopes associated with X_a, X_b and X_n respectively. X_a, X_b and X_n are independent variables and e is error.

For prediction of the strength of the green mortar before preparation it, the strength was considered as dependent variable, while the proportion of WGP, SG, SF, SIF, HHF, SNF, UPV, Density and curing time were considered as independent variables in this study. The enter techniques in SPSS program were used to create the regression models. The data analysis was done using MLRA. The number of important statistical parameters were associated with the MLRA. Some of these parameters were coefficient of regression determination, model error, the significance level, the confidence level, the t-distribution and the F-distribution. Detailed explanations of these important parameters can be found in previous studies (81). As a final approach; regression models were created to predict the strength of green mortars. The statistical parameters of regression models were calculated at the 95% confidence level. Summary of regression models were shown in Table 7. Predictive models of the strength of green mortar were given below:

$$CS=35.033-(0.056\times WGP)-(0.116\times SG)-(0.042\times SF)+(0.235\times Age)$$ Model 1

$$CS=-174.051+(8.276\times UPV)+(0.078\times DS)$$ Model 2

$$CS=-169.385-(0.021\times WGP)-(0.052\times SG)+(0.093\times DS)$$ Model 3

$$CS=-25.892+(9.361\times FS)-(0.208\times Age)$$ Model 4

$$CS=36.257-(0.358\times WGP)-(0.701\times SG)+(0.235\times Age)$$ Model 5

$$FS=6.335-(0.002\times WGP)-(0.011\times SG)+(0.003\times SF)+(0.047\times Age)$$ Model 6

$$FS=3.393+(0.085\times CS)+(0.027\times Age)$$ Model 7

$$FS=-17.243+(0.011\times DS)$$ Model 8

Where, CS and FS is compressive strength (MPa) and flexural strength (MPa) of green mortar respectively, UPV and DS is the ultrasonic pulse velocity (km/sec) and density of green mortar respectively, WGP is the content of waste glass powder (%), SG is the content of steel slag (%), SF is the content of silica fume (%).

To assess the validity of the predictive models mentioned above; the behavior of correlation (R), determination of coefficient (R2), the t-test, the F-test and Multicollinearity-test were considered. The statistical parameters of regression models of green mortar were shown in Table 7.

The correlation coefficient(R) for all predictive models of non-reinforced and reinforced green mortar appear to lie in acceptable range. The value of determination coefficient (R2) of all regression models (1-8) for non-reinforced green mortar was 0.813, 0.921, 0.958, 0.813, 0.792, 0.810, 0.885 and 0.725 respectively. And, for reinforced green mortars, the value of determination coefficient (R2) of all regression models (1-6) was 0.952, 0.952, 0.965, 0.866, 0.824 and 0.819 respectively. A high

Table 7: Regression models of green mortar (at the 95% confidence level)

Model No.	Dependent variable	Independent variable	Coefficient	t-value	t-significant	Determination coefficient		Model error	F-value	F-significant	Collinearity statistics	
						R	R^2				Tolerance	VIF
1	CS	Constant	35.033	24.516	0.000	0.897	0.805	2.968	34.110	0.000	-	-
		WGP	-0.056	-3.617	0.001						0.903	1.108
		SG	-0.116	-8.806	0.000						0.923	1.084
		SF	-0.042	1.742	0.091						0.853	1.172
		Age	0.235	5.130	0.000						1.000	1.000
2	CS	Constant	-174.051	-4.422	0.000	0.960	0.921	1.719	93.158	0.000	-	-
		Density	0.078	3.315	0.004						0.164	6.085
		UPV	8.276	2.337	0.033						0.164	6.085
3	CS	Constant	-169.385	-6.768	0.000	0.979	0.959	1.330	81.059	0.000	-	-
		WGP	-0.021	-2.028	0.062						0.834	1.199
		SG	-0.052	-4.616	0.000						0.509	1.965
		SF	-0.001	-0.034	0.973						0.785	1.275
		Density	0.093	8.418	0.000						0.447	2.239
4	CS	Constant	-25.892	-5.430	0.000	0.907	0.813	2.742	81.627	0.000	-	-
		FS	9.361	11.514	0.000						0.549	1.823
		Age	-0.208	-3.634	0.001						0.549	1.823
5	CS	Constant	36.257	28.464	0.000	0.890	0.792	3.017	43.227	0.000	-	-
		WGP	-0.358	-4.261	0.000						0.996	1.004
		SG	-0.701	-9.535	0.000						0.996	1.004
		Age	0.235	5.032	0.000						1.000	1.000
6	FS	Constant	6.335	37.615	0.000	0.897	0.805	0.350	34.082	0.000	-	-
		WGP	-0.002	-1.248	0.221						0.903	1.108
		SG	-0.011	-7.074	0.000						0.923	1.084
		SF	0.003	0.901	0.374						0.853	1.172
		Age	0.047	8.743	0.000						1.000	1.000
7	FS	Constant	3.393	15.284	0.000	0.941	0.885	0.260	135.230	0.000	-	-
		CS	0.085	11.514	0.000						0.845	1.183
		Age	0.027	6.267	0.000						0.845	1.183
8	FS	Constant	-17.243	-4.744	0.000	0.852	0.725	0.294	44.845	0.000	-	-
		Density	0.0110	6.697	0.000						1.000	1.000

value for the correlation coefficient of predictive model does not necessarily to express the good performance of model (49). The value of determination coefficient (R2) does not establish the validity of predictive model unless the results of test for significance of regression, t-test and Multicollinearity-test show the consistency between the experimental results and predictive model. Therefore, test for significance of regression, t-test and Multicollinearity-test were considered.

Test for significance of regression was carried out using analysis of variance (F-test).This test was helped to determine whether the regression line was the most suitable curve in representing the relationship between the sample data sets of two correlated variables (48). The null hypothesis was designated Ho=0, which means that no correlation exists between the two variables tested using analysis of variance. The analysis of variance produced two values for each model: an F-value, which indicates the degree to which the regression equation fits the data, and a second value that indicates the statistical significance of the F-value. In the case that the statistical significance of the F-value was less than 0.05 at the 95% confidence level, Ho=0 was refused, meaning that the relationship between depended variable and the target independent variable could be expressed as a linear or non-linear equation at the 95% confidence level (49).

Otherwise, it was assumed that the relationship could not be represented as a regression model (50). Therefore, all the predictive models in Table 7 are considered to be valid due to the significance of the F-value was less than 0.05 for all these models.

The t-test was used to examine the significance of the variables in each model at the 95% confidence level. By considering the degrees of freedom for each variable, a t-value calculated for the experimental data can be compared with a tabulated t-value. In case that the calculated t-value is greater than the tabulated value, the significance of t-values was less than 0.05 at the 95% confidence level and the variable is considered to be significant to the model (50).The t-significance value of all predictive models for green mortars (except Model 1, 3 and 6) was less than 0.05at the 95% confidence level. Therefore, Models-2, Model-4, Model-5, Model-7 and Model-8 of green mortars are considered to be valid. For green mortars; Model-1, SF exceeds 0.05 (0.091). For Model-3, WGP and SF exceed 0.05, The t-significance value was 0.062 and 0.973 respectively. For Model-6, WGP and SF exceed 0.05, The t-significance value was 0.221 and 0.374 respectively. Based on the obtained t-significance values, all the regression models of green mortar are valid except for Models 1, 3 and 6 in Table 7.

Multicollinearity is a statistical phenomenon in which there exists a perfect or exact relationship between the predictor variables. In the other words, it means two or more of the independent variables in a multiple regression model are highly correlated (25,34). This causes a problem in the interpretation of the regression results. Multicollinearity was tested using Tolerance(T) and the variance inflation factor (VIF). Tolerance is the amount of variability in one independent variable that is no explained by the other independent variables (56,63). Tolerance values less than 0.10 indicate to the presence of multicollinearity. The variance inflation factor (VIF)is defined as the inverse of Tolerance (1/T). In case that the (VIF) is more than 5, the multicollinearity has been presented. Tolerance values of all predictive models of green mortars were more than 0.1.

The variance inflation factors (VIF) of all predictive models in Table 7 were less than 5, except Model-2 of green mortar. For this model, the variance inflation factor of UPV and Density was 6.085 and 6.085 respectively. Therefore, Model-2 of green mortar was considered invalid because of multicollinearity problems.

AHP and TOPSIS methodology

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision making approach which organizes and analyzes complex decisions (50). It was developed by Thomas Saaty in the 1970, 1980 and 1990 (51). The decision problem in this approach is arranged in hierarchic structure (51). The arrangement is in the descending form from an overall goal to criteria, sub-criteria and alternatives in successive levels (52). In this paper, AHP was used to evaluate the weight of the thirteen (13) criteria of reinforced green mortars and non-reinforced green mortars. Five (5) of them were compressive strength, Flexural strength, UPV and Cost of reinforced green mortars and another eight (8) were Raw materials, Electricity energy, Thermal energy, CO_2, Dust, Waste glass, Steel slag and Silica fume of green mortars. The criteria weights of green mortars were computed using the following general steps:

Step 1: Conduct the comparison for two criteria at the same time with respect their impact on the mortar prepared. The comparison conducts based on the one common scale (adapted from Satty) that is displayed in Table 8. to build the Pair-wise comparison matrix (F).

The Pair-wise comparison matrix (F) builds by asking questions to experts or decision makers like, which criterion is more important with regards to the decision goal. The answers to these questions will construct the matrix (F) as shown below:

$$F=\begin{matrix} & C_1 & C_2 & \cdots & C_m \\ C_1 & f_{11} & f_{12} & \cdots & f_{1m} \\ C_2 & f_{21} & f_{22} & \cdots & f_{2m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C_m & f_{m1} & f_{m2} & \cdots & f_{mm} \end{matrix} = (fij)_{m\times m}$$

where *fij* represents a quantified judgment on Ci/Cj with fii = 1 and fij = 1/fji for i, j = 1, . . .,m

Step 2: Compute the sum $\sum_{i=1}^{4}$fij for each column in matrix (F). Then, divide (Fij) to computed sum according to Eq.1, the result will be matrix (X):

$$xij=\frac{Fij}{\sum_{i=1}^{m}Fij}(i=1,2...4,\ j=1,2...4) \quad (1)$$

Table 8: One common scale (adapted from Saaty) used in this study

	Definition					
	Equal importance	Somewhat more important	Much more important	Very much more important	Absolutely more important	Intermediate Values
Intensity of importance	1	3	5	7	9	2, 4, 6, 8

$$X=\begin{matrix} & C_1 & C_2 & \cdots & C_m \\ C_1 \\ C_2 \\ \vdots \\ C_m \end{matrix}\begin{Bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mm} \end{Bmatrix}$$

Step 3: Calculate the average of each raw in the matrix (X) to obtain the weight (*w*) of each criterion.

Step 4: Check the consistency of the pairwise comparison matrix (F) by using the following steps:

a. Construct matrix (Y) by multiplying the criterion weight (*w*) with pairwise comparison matrix (F).

$$Y=\begin{matrix} & C_1 & C_2 & \cdots & C_m \\ C_1 \\ C_2 \\ \vdots \\ C_m \end{matrix}\begin{Bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1m} \\ Y_{21} & Y_{22} & \cdots & Y_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ Y_{m1} & Y_{m2} & \cdots & Y_{mn} \end{Bmatrix}$$

Where *Yij* represents the result of the multiplying *fij* by wj, i=1,…,m; j=1,…,m.

b. Calculate the sum of each raw ($\sum_{j=1}^{4} Yij$) in the matrix (*Y*). The result will be (*S*).

$$S=\begin{Bmatrix} S_1 \\ S_2 \\ \vdots \\ S_m \end{Bmatrix}$$

c. Divide the calculated sum of each raw (*S*) o criterion weight (*wi*). The result will be (*S/W*)

$$S/W=\begin{Bmatrix} S_1/w_1 \\ S_2/w_2 \\ \vdots \\ S_m/w_m \end{Bmatrix}$$

d. Compute the consistency index (CI) according to Eq. 2.

$$CI=\frac{\left(\frac{\sum_{i=1}^{m}(S/w)ij}{m}\right)-m}{m-1} \quad \text{(where, m is number of compared criteria)} \quad (2)$$

The random consistency index (RCI) is obtained using Table 9 (Saaty (52)). Based on the number of the criteria used in AHP method, the random consistency index is determined. The consistency ratio (CR) is computed by dividing (CI) to (RC). If the consistency ratio (CR) is ≤0.1 ,the pair wise comparison matrix (F) is considered to have an acceptable trust worthy and consistency; otherwise, it required to be revised (53).

Technique for Order Performance by Similarity to Ideal Solution (TOPSIS)

TOPSIS is a simple and useful approach which is used to deal with the complex system related to making a best choice among several alternatives (54). It was developed by Ching-Lai Hwang and Yoon in 1981. The concept of this technique is based on the selecting the ideal alternative which has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (55). In this research, TOPSIS was used to select and rank the best of reinforced green mortar based on its properties. In addition this technique was also used to determine and rank the best and worst non-reinforced green mortar based on its impact on the environment. The ranking and determining of reinforced and non-reinforced green mortars was achieved using the following steps:

Step 1: Construct the decision matrix (N) for ranking of the alternatives, the structure of matrix can be expressed as follow:

$$N=\begin{matrix} & C_1 & C_2 & \cdots & C_n \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix}\begin{Bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ Z_{m1} & Z_{m2} & \cdots & Z_{mn} \end{Bmatrix}$$

where Ai represents the alternatives i, i = 1…., m; Cj represents the criteria that are required on which the alternative is judged, j=1…, n; Zij represents jth attribute, j=1, n related to i, the alternative; and Zij is the obtained value representing the performance rating of each alternative Ai with respect to each requirement Cj.

Step 2: Calculate the normalized decision matrix (V): The raw data can be normalized by utilizing Eq. 3. to produce the matrix (V).

$$Vij=\frac{nif}{\sqrt{\sum_{i=1}^{m} nij^2}} \quad \text{where i=1, 2, 3,...,m and j=1, 2, 3,…,n} \quad (3)$$

Step 3: Compute the weighted normalized decision matrix (B) by multiplying the weights of criteria (w) with the normalized decision matrix (V). In this paper, the weights of criteria (w) were previously calculated based on AHP method.

Step 4: determine the positive ideal reference point (A+) and negative ideal reference point (A-) respectively.

$A^+=\{a_1^+, a_2^+ \ldots\ldots a_n^+\}=\{(\max bij \mid j\in Cb), (\text{mini } bij \mid j\in CP)\}$

$A^-=\{a_1^-, a_2^- \ldots\ldots a_n^-\}=\{(\text{mini } bij \mid j\in Cb), (\max bij \mid j\in CP)\}$

where *Cb* is benefit-type attributes (the higher value is the better) and *Cp* is benefit -type attribute (the lower

Table 9: Values of the Random Consistency Index (RCI) for small problems

	Number of criteria								
	2	3	4	5	6	7	8	9	10
Random Consistency Index	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

value is the better).

Step 5: Compute the distance of all alternatives to the positive and negative ideal reference point (D+ and D-) by using Eq. 4 and Eq.5 respectively.

$$Di^{+}=\sqrt{\sum_{j=1}^{n}(bij\text{-}aj^{+})^{2}} \quad (4)$$

$$Di^{-}=\sqrt{\sum_{j=1}^{n}(bij\text{-}aj^{-})^{2}} \quad (5)$$

Step 6: Calculate the relative closeness coefficient (*R*) of each alternative to the ideal reference point by using Eq. 4. Then, conduct the outranking of the alternatives in descending order. The larger value of *Ri* indicates to the better performance of the alternative.

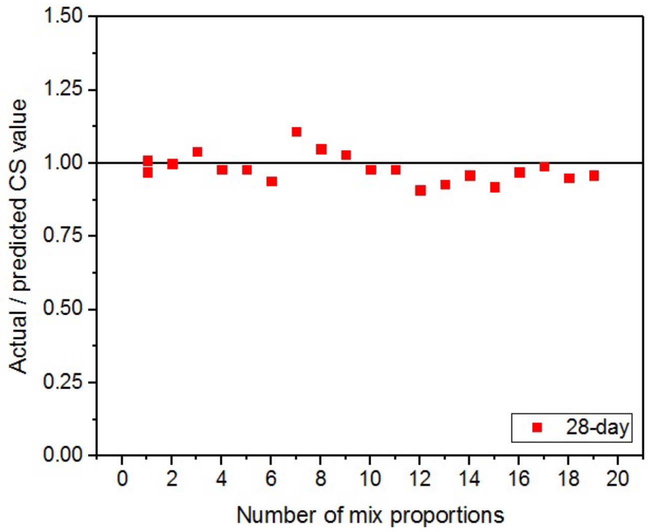
$$Ri=\frac{Di-}{(Di+)+(Di-)} \quad (6)$$

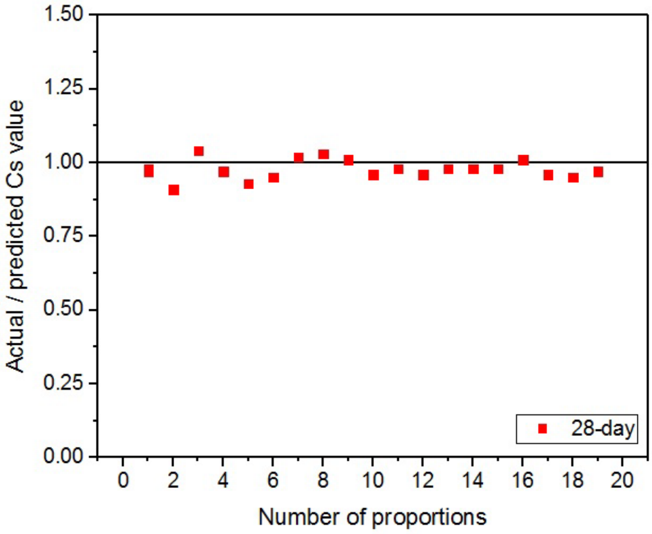
Performance of the regression models to predict strength parameters

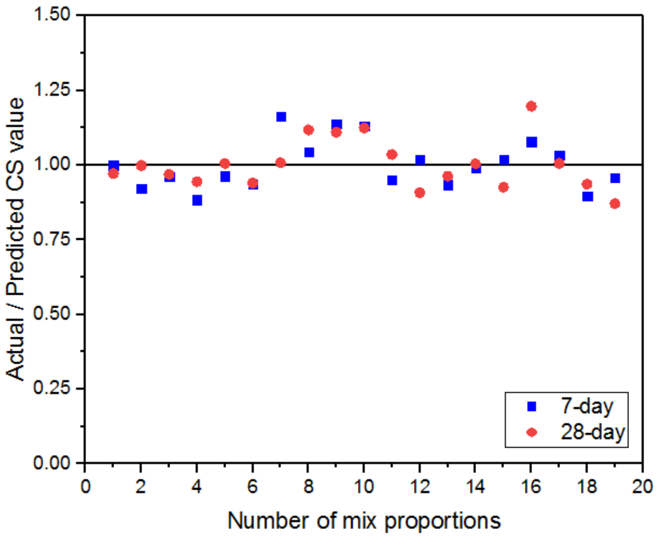
The strength of green mortar can be predicted using regression models. For prediction the strength of such green mortar, it is possible to use Model-4, Model-5, Model-7 and Model-8 in Table 10. The comparison between the obtained strength from the experimental results and regression models was illustrated in Fig. 1. The statistical parameters of valid regression models are shown in Table 10.

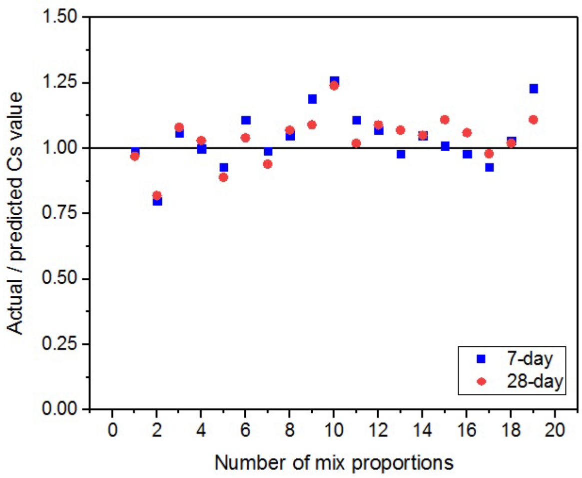
Table 10: Performance of the predicted models

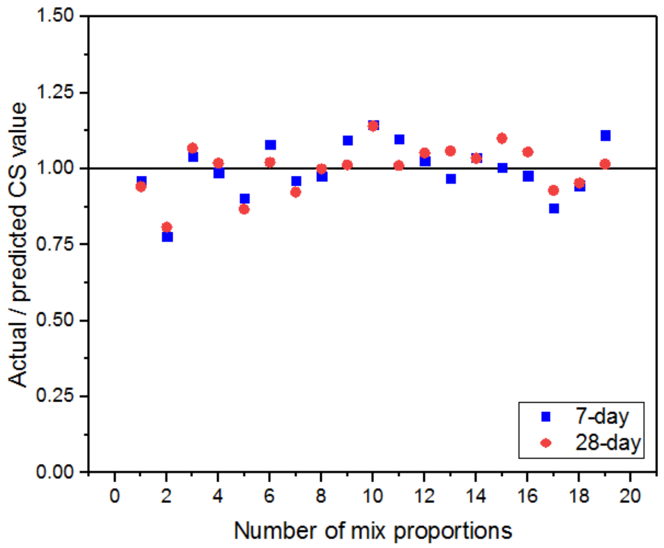
Models of non re-inforced mortars		Mean	Standard Devia-tion (SD)	Mean of standard error	Standard Devia-tion of standard error
Model-4	CS	32.196	5.763	0.761	0.129
Model-5	CS	32.196	5.646	0.968	0.187
Model-7	FS	6.594	0.704	0.072	0.015
Model-8	FS	7.091	0.463	0.088	0.036

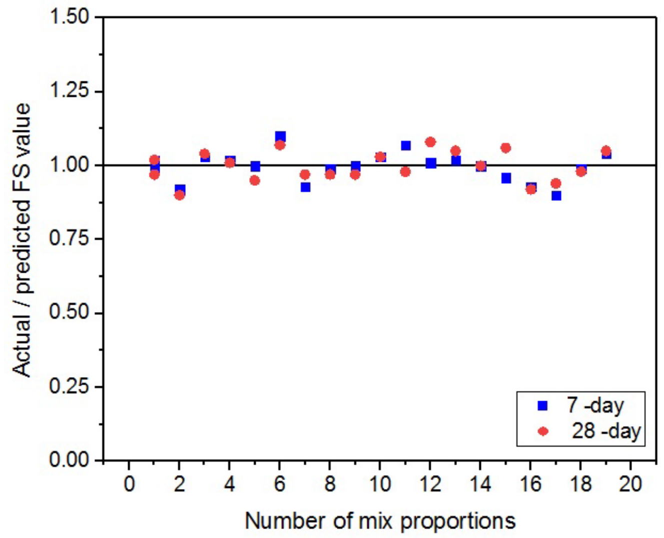


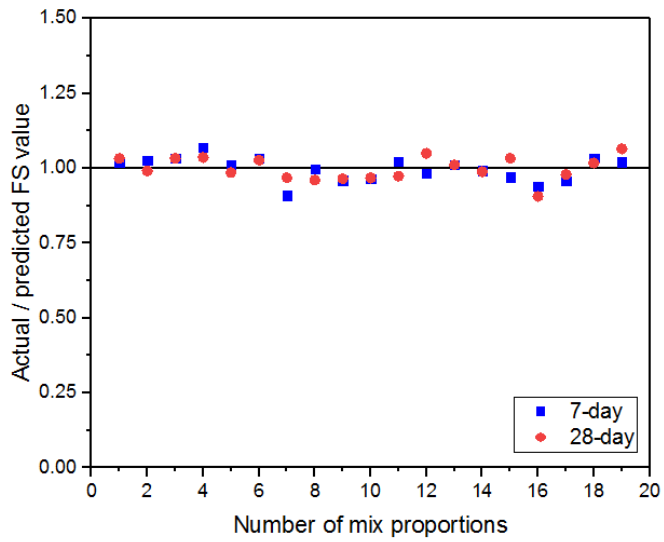












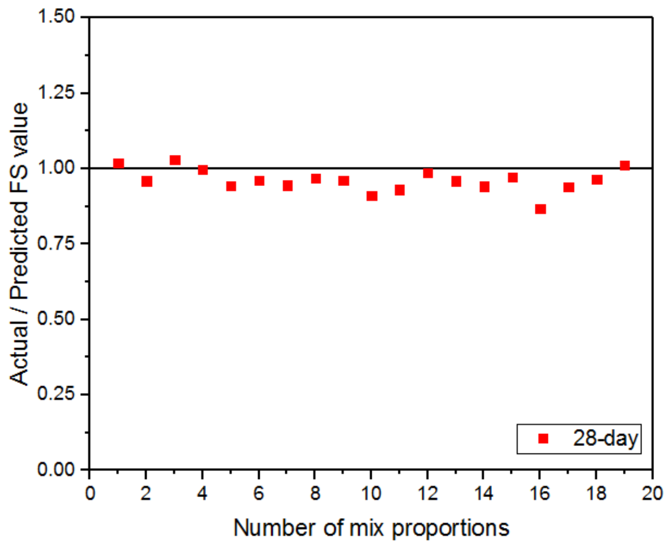


Figure 1: Comparison of strength parameters predict for green mortars

Impact assessment of the traditional mortar and green mortars on the environment

In order to assess the impact of the traditional mortar (it has not contained a partial replacement of cement) and green mortar on the environment, the integrated AHP and TOPSIS method was used. Based on the non-renewable resource consumed, air pollutants emitted during cement industry and the solid waste used as replacement of cement, the environmental impact of mortars was assessed in this study. The non-renewable resources consumed were raw materials, electricity energy and thermal energy required cement industry. Air pollutants were carbon dioxide and dust emitted during cement production. The solid wastes used as a partial replacement of cement were: waste glass, steel slag and silica fume. Therefore the eight criteria were considered. The evaluated weight of each criterion based on AHP method was listed in Table 11. In order to check the pair-wise comparison matrix, that was shown in Table 12. According to AHP method, the weight of these criteria (Raw materials, electricity energy, Thermal energy, CO2, Dust, Waste glass, Steel slag, and silica fume) was computed. The matrices, that are obtained through applying of AHP method, were shown in Table 13., the step 4 that was mentioned previously in the general steps of AHP method, was applied as shown in Table 14. Therefore, the calculated consistency index was 0.082041 and the random consistency index obtained from Table 15 was 1.41. Consequently, the consistency ratio was 0.058. Due the consistency ratio was below 0.1, the pair-wise comparison matrix was considered. Then, the general steps of TOPSIS technique were applied to rank and select the best of the green mortar based on its impact on the environment. The raw data considered in TOPSIS technique were listed in Table 16. The matrices and results obtained through this technique were shown in Table 16-21.

Table 21 and Fig.2 have shown that the 19th mix of green mortar is the best as it got the rank 1 and the first mix is the worst mix as it got the rank 19.

Table 11: The criteria weights evaluated by AHP method

Criteria								
	Raw materials	Electricity energy	Thermal energy	CO_2	Dust	Waste glass	Steel slag	Silica fume
Weight	0.17	0.08	0.13	0.13	0.09	0.12	0.20	0.08

Table 12: The pair-wise comparison matrix (F) of green mortars criteria

	Raw materials	Electricity energy	Thermal energy	CO_2	Dust	Waste glass	Steel slag	Silica fume
Raw materials	1	2	1	1	1	2	2	2
Electricity energy	1/2	1	1/2	1/2	1	1/2	1/2	2
Thermal energy	1	2	1	1	2	1	0.5	1
CO_2	1	2	1	1	2	2	1/3	1
Dust	1	1	1/2	1/2	1	1	1/3	1
Waste glass	1/2	2	1	1/2	1	1	1/2	3
Steel slag	1/2	2	2	3	3	2	1	2
Silica fume	1/2	1/2	1	1	1	1/3	1/2	1

Table 13: Matrix X obtained from AHP method for green mortars criteria

	Raw materials	Electricity energy	Thermal energy	CO_2	Dust	Waste glass	Steel slag	Silica fume
Raw materials	0.166667	0.16	0.125	0.117647	0.083333	0.20339	0.352941	0.153846
Electricity energy	0.083333	0.08	0.0625	0.058824	0.083333	0.050847	0.088235	0.153846
Thermal energy	0.166667	0.16	0.125	0.117647	0.166667	0.101695	0.088235	0.076923
CO_2	0.166667	0.16	0.125	0.117647	0.166667	0.20339	0.058824	0.076923
Dust	0.166667	0.08	0.0625	0.058824	0.083333	0.101695	0.058824	0.076923
Waste glass	0.083333	0.16	0.125	0.058824	0.083333	0.101695	0.088235	0.230769
Steel slag	0.083333	0.16	0.25	0.352941	0.25	0.20339	0.176471	0.153846
Silica fume	0.083333	0.04	0.125	0.117647	0.083333	0.033898	0.088235	0.076923

Table 14: Matrix Y for checking the pair-wise comparison matrix evaluated in AHP method

	Raw materials	Electricity energy	Thermal energy	CO_2	Dust	Waste glass	Steel slag	Silica fume	Si	Si/wi
Raw materials	0.17	0.16	0.13	0.13	0.09	0.24	0.4	0.16	1.48	8.705882
Electricity energy	0.085	0.08	0.065	0.065	0.09	0.06	0.1	0.16	0.705	8.812500
Thermal energy	0.17	0.16	0.13	0.13	0.18	0.12	0.1	0.08	1.07	8.230769
CO_2	0.17	0.16	0.13	0.13	0.18	0.24	0.066667	0.08	1.156667	8.897438
Dust	0.17	0.08	0.065	0.065	0.09	0.12	0.066667	0.08	0.736667	8.185189
Waste glass	0.085	0.16	0.13	0.065	0.09	0.12	0.1	0.24	0.99	8.250000
Steel slag	0.085	0.16	0.26	0.39	0.27	0.24	0.2	0.16	1.765	8.825000
Silica fume	0.085	0.04	0.13	0.13	0.09	0.04	0.1	0.08	0.695	8.687500

Table 15: Values of the Random Consistency Index (RCI) for small problems

	Number of criteria								
	2	3	4	5	6	7	8	9	10
Random Consistency Index	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Table 16: The alternatives and criteria used in TOPSIS method

Number of mix	Raw materials (Kg/m^3)	Electricity Energy (KWh)	Thermal energy (Mj)	CO_2 (Kg/m^3)	Dust (Kg/m^3)	Waste glass (Kg/m^3)	Steel slag (Kg/m^3)	Silica fume (Kg/m^3)
1	902	51	1268	299	92	0	0	0
2	808	46	1135	268	82	56	0	0
3	760	43	1068	252	78	84	0	0
4	712	41	1001	236	73	112	0	0
5	818	47	1149	271	83	0	57	0
6	775	44	1088	257	79	0	86	0
7	731	42	1028	243	75	0	115	0
8	843	48	1185	280	86	0	0	34
9	822	47	1156	273	84	0	0	45
10	803	46	1129	267	82	0	0	56
11	725	41	1019	241	74	45	68	0
12	722	41	1014	240	74	45	68	0
13	727	41	1021	241	74	29	85	0
14	704	40	990	234	72	57	68	0
15	676	38	949	224	69	71	71	0
16	679	39	954	225	69	57	85	0
17	666	38	936	221	68	45	68	34
18	647	37	909	215	66	45	67	45
19	628	36	882	208	64	45	67	56

Table 17: Decision matrix (N) obtained from TOPSIS method for selection of the best alternative

	Raw materials	Electricity energy	Thermal energy	CO_2	Dust	Waste glass	Steel slag	Silica fume
A_1	902	51	1268	299	92	0	0	0
A_2	808	46	1135	268	82	56	0	0
A_3	760	43	1068	252	78	84	0	0
A_4	712	41	1001	236	73	112	0	0
A_5	818	47	1149	271	83	0	57	0
A_6	775	44	1088	257	79	0	86	0
A_7	731	42	1028	243	75	0	115	0
A_8	843	48	1185	280	86	0	0	34
A_9	822	47	1156	273	84	0	0	45
A_{10}	803	46	1129	267	82	0	0	56
A_{11}	725	41	1019	241	74	45	68	0
A_{12}	722	41	1014	240	74	45	68	0
A_{13}	727	41	1021	241	74	29	85	0
A_{14}	704	40	990	234	72	57	68	0
A_{15}	676	38	949	224	69	71	71	0
A_{16}	679	39	954	225	69	57	85	0
A_{17}	666	38	936	221	68	45	68	34
A_{18}	647	37	909	215	66	45	67	45
A_{19}	628	36	882	208	64	45	67	56

Table 18: Normalized decision matrix (V) obtained from TOPSIS method

	Raw materials	Electricity energy	Thermal energy	CO_2	Dust	Waste glass	Steel slag	Silica fume
A_1	0.276631	0.274567	0.276735	0.276327	0.27646	0	0	0
A_2	0.247803	0.247648	0.247708	0.247678	0.24641	0.263282	0	0
A_3	0.233082	0.231498	0.233086	0.232891	0.23439	0.394924	0	0
A_4	0.218361	0.22073	0.218464	0.218105	0.219365	0.526565	0	0
A_5	0.25087	0.253032	0.250764	0.250451	0.249415	0	0.214166	0
A_6	0.237682	0.236881	0.237451	0.237512	0.237395	0	0.323128	0
A_7	0.224188	0.226114	0.224356	0.224574	0.225375	0	0.43209	0
A_8	0.258537	0.258416	0.258621	0.258768	0.25843	0	0	0.302488
A_9	0.252096	0.253032	0.252292	0.252299	0.25242	0	0	0.400352
A_{10}	0.246269	0.247648	0.246399	0.246754	0.24641	0	0	0.498216
A_{11}	0.222348	0.22073	0.222392	0.222725	0.22237	0.211566	0.255497	0
A_{12}	0.221428	0.22073	0.221301	0.221801	0.22237	0.211566	0.255497	0
A_{13}	0.222961	0.22073	0.222828	0.222725	0.22237	0.136343	0.319371	0
A_{14}	0.215907	0.215347	0.216063	0.216256	0.21636	0.267984	0.255497	0
A_{15}	0.20732	0.204579	0.207115	0.207015	0.207345	0.333805	0.266768	0
A_{16}	0.20824	0.209963	0.208206	0.207939	0.207345	0.267984	0.319371	0
A_{17}	0.204253	0.204579	0.204278	0.204242	0.20434	0.211566	0.255497	0.302488
A_{18}	0.198426	0.199196	0.198385	0.198697	0.19833	0.211566	0.251739	0.400352
A_{19}	0.192599	0.193812	0.192492	0.192228	0.19232	0.211566	0.251739	0.498216

Table 19: The weighted normalized decision matrix (B) obtained from TOPSIS method

	Raw materials	Electricity energy	Thermal energy	CO_2	Dust	Waste glass	Steel slag	Silica fume
A_1	0.047027	0.021965	0.035976	0.035923	0.024881	0	0	0
A_2	0.042126	0.019812	0.032202	0.032198	0.022177	0.031594	0	0
A_3	0.039624	0.01852	0.030301	0.030276	0.021095	0.047391	0	0
A_4	0.037121	0.017658	0.0284	0.028354	0.019743	0.063188	0	0
A_5	0.042648	0.020243	0.032599	0.032559	0.022447	0	0.042833	0
A_6	0.040406	0.01895	0.030869	0.030877	0.021366	0	0.064626	0
A_7	0.038112	0.018089	0.029166	0.029195	0.020284	0	0.086418	0
A_8	0.043951	0.020673	0.033621	0.03364	0.023259	0	0	0.024199
A_9	0.042856	0.020243	0.032798	0.032799	0.022718	0	0	0.032028
A_{10}	0.041866	0.019812	0.032032	0.032078	0.022177	0	0	0.039857
A_{11}	0.037799	0.017658	0.028911	0.028954	0.020013	0.025388	0.051099	0
A_{12}	0.037643	0.017658	0.028769	0.028834	0.020013	0.025388	0.051099	0
A_{13}	0.037903	0.017658	0.028968	0.028954	0.020013	0.016361	0.063874	0
A_{14}	0.036704	0.017228	0.028088	0.028113	0.019472	0.032158	0.051099	0
A_{15}	0.035244	0.016366	0.026925	0.026912	0.018661	0.040057	0.053354	0
A_{16}	0.035401	0.016797	0.027067	0.027032	0.018661	0.032158	0.063874	0
A_{17}	0.034723	0.016366	0.026556	0.026551	0.018391	0.025388	0.051099	0.024199
A_{18}	0.033732	0.015936	0.02579	0.025831	0.01785	0.025388	0.050348	0.032028
A_{19}	0.032742	0.015505	0.025024	0.02499	0.017309	0.025388	0.050348	0.039857

Table 20: The positive and negative ideal reference point for each criterion

	Raw material	Electricity energy	Thermal energy	CO_2	Dust	Waste glass	Steel slag	Silica fume
a_i^+	0.032742	0.015505	0.025024	0.02499	0.017309	0.063188	0.086418	0.039857
a_i^-	0.047027	0.021965	0.035976	0.035923	0.024881	0	0	0

Table 21: The distance to the positive and negative ideal reference point (Di^+ and Di^-), relative closeness coefficient (Ri) to the ideal reference point and the ranking for each alternative

Number of mix	Alternative	Di^+	Di^-	Ri	Alternative Ranking
1	A_1	0.116585	0	0	19
2	A_2	0.101433	0.032592	0.243179	16
3	A_3	0.097123	0.048898	0.33487	13
4	A_4	0.095442	0.065196	0.405857	12
5	A_5	0.087992	0.043422	0.330421	14
6	A_6	0.078817	0.065523	0.453949	11
7	A_7	0.075236	0.087609	0.53799	6
8	A_8	0.109738	0.024701	0.183734	18
9	A_9	0.108616	0.032722	0.231516	17
10	A_{10}	0.1081	0.040713	0.273585	15
11	A_{11}	0.065827	0.059005	0.472675	10
12	A_{12}	0.0658	0.059061	0.473014	9
13	A_{13}	0.066026	0.067607	0.505915	7
14	A_{14}	0.061979	0.062664	0.502748	8
15	A_{15}	0.05686	0.069449	0.549834	4
16	A_{16}	0.055485	0.07398	0.571429	2
17	A_{17}	0.054148	0.065136	0.546058	5
18	A_{18}	0.052858	0.068362	0.56395	3
19	A_{19}	0.052248	0.072874	0.582424	1

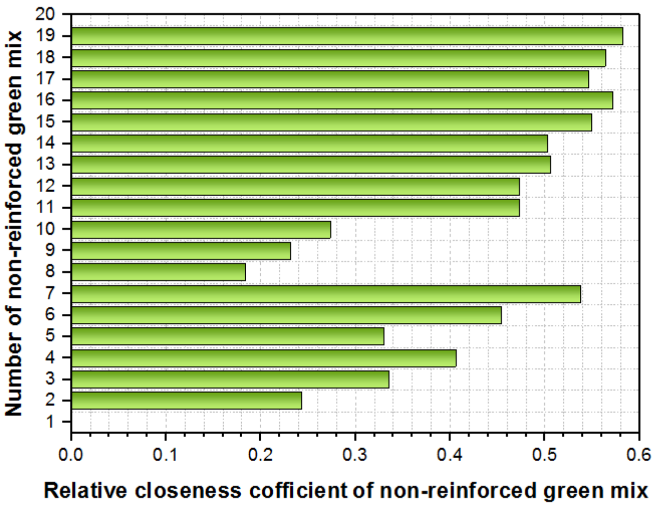


Figure 2: Closeness coefficient of non-reinforced green mortars

CONCLUSIONS

The study shows very interesting analytical equations that indicate significant relationships between each of compressive and flexural strengths for green mortar with different parameters used in the production of green mortar mixes. Such parameters included the age of the mortar, density, UPV, SF, WGP, SG and SF. The statistical parameters of regression models were calculated at the 95% confidence level. Besides, based on integrated AHP and TOPSIS method have shown dramatic methods or the selection of the most important mortar mix that exhibit the best performance in ecological effects. Thus, the mix M19 which contains 70%OPC+8%WGP+12%SG+10% SF is classified as the best green mortar and the control mortar mix is the worst green mortar in terms of their impact on the environment.

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