Research Article

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Behavior of non-reinforced and reinforced green mortar with fibers

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Abstract: The behavior of non-reinforced green mortar with fibers has been observed. Different green mortar mixes have been prepared using different percentages of waste glass powder (WGP), steel slag (SG) and silica fume (SF). The properties of flow, density, ultrasonic pulse velocity (UPV), compressive and flexural strengths have been tested for such green mortar in the first phase of the experimental work. The selected green mortar mix that gives good properties with the acceptable ranges of cement replacement by such cementitious materials has been utilized to achieve the second phase of the experimental work. Thus, the uses of human hair fibers, sisal fibers and stainless steel nails fibers in the form of individual and hybrid fibers system and testing for the same properties mentioned above have been performed. The third phase includes the cost estimation for the said mortar. Whereas, the last phase deals with analysis of the results using the integrated AHP and TOPSIS method for selection the best performance of the green mortar. The results of mono sisal fiber, human hair fiber and stainless nails fiber by 0.75, 0.75 and 2% of volume fraction respectively, exhibited the highest increase in compressive strength, flexural strength, UPV and density compared with other percentages.

Keywords: Green mortar, Sisal fibers, Human hair fibers, TOPSIS

1 Introduction

Cement is the one of the most produced materials in the world. Annual global cement production has been estimated at 4.15 billion tons in 2016, and is expected to in-

crease to 4.25 billion tons per year in 2030 [1]. The production of this material requires the use of a huge amount of raw materials (limestone, clay and etc), energy (electricity and heat) and fossil fuels (natural gas, fuel oil, coal or some wastes) in addition to air and water [2–4]. The high quantity of 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_x), sulfur oxides (SO_x) and dust emissions in addition to the other air pollutants are released from cement manufacturing [5–8]. Approximately 8% of global carbon dioxide (CO_2) emission is released 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 or/and concrete workability, early and long term strength and long term durability [20–22]. Phys-

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ical 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, 27] 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]. The high content of amorphous silicon dioxide and very fine particles of silica fume are responsible for its high pozzolanic activity [33, 36]. The amorphous silicon dioxide reacts with calcium hydroxide, which is resulted from hydration cement, and lead to produce calcium silicate hydrate (C-S-H). The fine particles size of silica fume can fill the gap between cement particles. Thus, silica fume have significant role on the density of the interfacial transition zone between cement paste and fine aggregate which lead to enhance the microstructure of cement mortar and concrete [33]. Utilization of SF, SG and WGP as a supplementary cementitious materials in binary, ternary blends has been studied by many researchers [37, 38]. They are observed that the use of the mixture of SF and WGP or SG as a partial replacement of cement led to relieve the retardation effect of waste glass powder or steel slag on the early hydration of cement and improve the microstructure of hardened cement paste at later ages. Thus, the use of Waste glass powder, Steel slag and Silica fume with cement in combination form can contribute to produce green mortar and enhance its overall performance. Therefore, the utilize SCMs were considered in this study.

Generally, Concrete and mortar are brittle materials with low tensile strength and low deformation capacity [39]. The incorporation of the fibers in cementitious matrix mainly improves tensile, flexural, impact strength and flexural toughness [40–42]. Industrial and natural fibers have been studied by many researchers [43–45]. Utilization of natural, renewable and low cost fibers instead of industrial and high cost fibers has resulted in many advantages such as reducing Carbon footprint of construction industry, reducing of raw materials consumption and economy [46]. Sisal fibers(SIF) is one of the natural/vegetable fibers which need a low degree of manufacturing for their processing in comparison with synthetic fibers [47, 48]. It can contribute to provide the same level of flexural

strength as synthetic fibers such as polypropylene fibers and gain ductility and flexural toughness to concrete and mortar [49]. Recently, human hair has been also used as fibers for reinforcing concrete or mortar [50, 51]. Many researchers [52–54] have reported that the reinforcing of concrete with human hair fiber(HHF) can enhance mechanical properties. The use of micro fibers such as human hair fibers (HHF) can delay the formation of micro cracks by enhancing the pre peak mechanical properties [55, 56]. Moreover, utilization of Sisal fibers and Human hair fibers has a positive impact on environmental and economic aspects [57]. The incorporation of steel fibers in concrete and mortar has been documented by many researchers [58, 59]. Although, this type of fibers have characterized by high elastic modulus, tensile strength, flexural rigidity and gain good properties to mortar and concrete. It is expensive compared with other types of fibers. So, Stainless steel nails (SIF) have been used as fibers instead of steel fibers in this study. Stainless steel nails fibers are recognized by low cost and good properties. Utilization this type of fibers can contribute to increase the compressive strength, flexural strength and other properties of concrete [42].

Several researchers [60, 61] 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 [62–64]. Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are one of these methods which were used to select the best reinforced green mortar based on its behavior and to rank the non-reinforced green mortars based on its cost.

Although, many literatures are available for combination silica fume and pozzolanic materials in the mortar or concrete, their utilization with three different types of the fibers (sisal fibers, human hair fibers and low cost stainless steel nails) to produce reinforced green mortar is still limited. The major objectives of this research can be summarized into three parts:

1. The investigation of the green mortar behavior produced from waste glass powder, steel slag and silica fume and reinforced with natural and cheap fibers.
2. Selecting and ranking the best green mortar based on its properties and cost.

2 Materials and Mix proportions

2.1 Materials

Ordinary Portland Cement (OPC) type (CEM I) of strength class 42.5N was used in this study. It is obtained from Sulaymaniyah cement factory, Bazian district, Kurdistan, Iraq. Clear waste glass powder and Steel slag powder (prepared by ball mill machine) were supplied from glass recycling plant and iron production factory, Mosul, Iraq respectively. The specific gravity and fineness of these materials were measured according to ASTM C188 [65] and ASTM C204 [66]. Chemical composition of both Clear waste glass powder (WGP) and steel slag (SG) powder were examined using a XRF-1800 Sequential X-ray fluorescence spectrometer. According to ASTM C618, ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) the minimum requirement for a standard pozzolana is 70% which is comparable with the results obtained for the clear waste glass and steel slag samples. As per ASTM standard mentioned above, the maximum limit of SO_3 , Loss on Ignition (LoI) and Moisture content is 4%, 10% and 3% re-

spectively. As list in Table 1, the SO_3 contents of clear waste glass powder and steel slag powder was less than the acceptable limit, Loss of ignition (LOI) and moisture content have been neglected. Minor compounds such as ZrO_2 , TiO_2 , CuO , Cr_2O_3 , NiO , MnO , As_2O_3 are also found in clear waste glass and steel slag samples under consideration, the amount of individual component was not more than 0.5%. Densified Micro-silica (SF) was procured from MSASA-Construction Solutions for Africa, Pomona AH, South Africa.

The chemical composition and physical properties of OPC, WGP, SG and SF are given in Table 1. The sand used for preparing of non-reinforced green mixes was prepared according to 20-30 sand requirements ASTM C778 [67]. Its specific gravity was measured according to ASTM C 128 [68] and was 2.590. Whereas, the sand used for preparing reinforced green mixes was prepared according to graded sand requirements ASTM C778 [67]. It was used to obtain a homogeneous mixture containing fibers, the specific gravity was 2.577. Superplasticizer obtained to enhance the workability of mixes was procured from Specialties construction chemicals factory, Jahra, Kuwait. Its commercial

Table 1: Physical properties and Chemical composition 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	4850	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 ($\text{K}_2\text{O} + \text{Na}_2\text{O}$) %	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	-	-	-

Table 2: Properties of superplasticizer

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

Figure 1: Fibers utilized in this study

Table 3: Fibers properties.

Properties	SIF	HHF	SNF
Average diameter (mm)	0.225	0.20	0.92
Average length (mm)	18±2	18±2	18±2
Specific gravity (gm/cm ³)	1.4	0.4	6.678

name is KUT PLAST PCE 600. The properties of superplasticizer are shown in Table 2. Tap water was utilized in all mixes.

Three different types of fibers used in this study were sisal fibers, human hair fibers and stainless steel nails in mono and hybrid fibers system. Sisal fibers (SIF) were brought in bundles form with length 1 meter approximately. They were separated and cut into (18 ± 2) mm before using them in the mixes. They were supplied from local markets, Mosul, Iraq. Human hair fibers (HHF) were obtained from local hair salons, Mosul, Iraq. They were washed, separated, combed and cut them into (18 ± 2) mm

before adding them to the mixes. Stainless steel nails (SNF) were procured from local markets, Mosul, Iraq (Figure 1). SIF and HHF were used in 0.5, 0.75 and 1% of volume fraction. (SNF) were used in 1, 1.5 and 2% of volume fraction. The properties of three different types of fibers are presented in Table 3.

2.2 Mix proportions

In this research, total forty one [41] mixes were prepared; Ten [10] of them were prepared to measure pozzolanic activity for each of waste glass powder, steel slag and silica fume. Binder/sand ratio was 1:2.75, water/binder ratio (W/B) was 0.59, and the mix proportions of these mixes are shown in Table 4.

Moreover, nineteen [19] mixes were prepared to produce non-reinforced green mortars, binder/sand ratio was 1:2.75, water + superplasticizer/binder ratio (W+SP/B) was

Table 4: Mortar mix proportions for measuring Pozzolanic activity.

Mix No.	Cement mixes (%)	OPC (kg/m ³)	WGP (kg/m ³)	SG (kg/m ³)	SF (kg/m ³)	Sand (kg/m ³)	W/B
1	100%OPC	508	0	0	0	1397	0.59
2	90%OPC+10%WGP	454	51	0	0	1389	0.59
3	85%OPC+15%WGP	428	75	0	0	1383	0.59
4	80%OPC+20%WGP	402	100	0	0	1381	0.59
5	90%OPC+10%SG	460	0	51	0	1405	0.59
6	85%OPC+15%SG	435	0	77	0	1408	0.59
7	80%OPC+20%SG	411	0	103	0	1414	0.59
8	94%OPC+6%SF	475	0	0	30	1389	0.59
9	92%OPC+8%SF	464	0	0	40	1386	0.59
10	90%OPC+10%SF	453	0	0	50	1383	0.59

Table 5: Mix proportions of non-reinforced green mortar.

Mix No.	Cement mixes (%)	OPC (Kg/m ³)	WGP (Kg/m ³)	SG (Kg/m ³)	SF (Kg/m ³)	Sand (Kg/m ³)	SP %	W+SP / B
U1	100%OPC	565	0	0	0	1554	2	0.39
U2	90%OPC+10%WGP	506	56	0	0	1546	2	0.39
U3	85%OPC+15%WGP	476	84	0	0	1540	2	0.39
U4	80%OPC+20%WGP	446	112	0	0	1535	2	0.39
U5	90%OPC+10%SG	512	0	57	0	1565	2	0.39
U6	85%OPC+15%SG	485	0	86	0	1570	2	0.39
U7	80%OPC+20%SG	458	0	115	0	1576	2	0.39
U8	94%OPC+6%SF	528	0	0	34	1546	2	0.39
U9	92%OPC+8%SF	515	0	0	45	1540	2	0.39
U10	90%OPC+10%SF	503	0	0	56	1537	2	0.39
U11	80%OPC+8%WGP+12%SG	454	45	68	0	1559	2	0.39
U12	80%OPC+10%WGP+10%SG	452	45	68	0	1554	2	0.39
U13	80%OPC+5%WGP+15%SG	455	29	85	0	1565	2	0.39
U14	78%OPC+10%WGP+12%SG	441	57	68	0	1557	2	0.39
U15	75%OPC+12.5%WGP+12.5%SG	423	71	71	0	1554	2	0.39
U16	75%OPC+10%WGP+15%SG	425	57	85	0	1559	2	0.39
U17	74%OPC+8%WGP+12%SG+6%SF	417	45	68	34	1551	2	0.39
U18	72%OPC+8%WGP+12%SG+8%SF	405	45	67	45	1546	2	0.39
U19	70%OPC+8%WGP+12%SG+10%SF	393	45	67	56	1543	2	0.39

Table 6: Mix proportions of reinforced green mortar used superplasticizer

Index	OPC (kg/m ³)	Sand (kg/m ³)	WGP (kg/m ³)	SG (kg/m ³)	SF (kg/m ³)	Sp. (%)	W+SP./B	SIF (%)	HHF (%)	SNF (%)
M0	358	1405	41	61	51	2	0.56	-	-	-
M1	358	1405	41	61	51	2	0.56	0.5	-	-
M2	358	1405	41	61	51	2	0.56	0.75	-	-
M3	358	1405	41	61	51	2	0.56	1	-	-
M4	358	1405	41	61	51	2	0.56	-	0.5	-
M5	358	1405	41	61	51	2	0.56	-	0.75	-
M6	358	1405	41	61	51	2	0.56	-	1	-
M7	358	1405	41	61	51	2	0.56	-	-	1
M8	358	1405	41	61	51	2	0.56	-	-	1.5
M9	358	1405	41	61	51	2	0.56	-	-	2
M10	358	1405	41	61	51	2	0.58	0.5	0.5	1.5
M11	358	1405	41	61	51	2	0.58	0.75	0.5	1

0.39, the mix proportions of these mixes are listed in Table 5.

Another twelve [12] mixes were prepared by substituting 8%, 12% and 10% of cement by WGP, SG and SF respectively and using three different types of fibers (sisal fibers, human hair fibers and stainless steel nails) with different percentages of volume fraction to produce reinforced green mortars, binder/sand ratio was 1:2.75, max-

imum superplasticizer dosage (2%) by weight of cement was also used in these mixes as listed in Table 6.

3 Methodology

3.1 Experimental method

Ten [10] mixes were prepared to measure the pozzolanic activity of solid waste materials (waste glass powder, steel slag and silica fume) by following steps: a) Cement and solid waste material were mixed for 1 to 2 minutes. b) Then, the sand was added and mixed with the mixture for 1 to 2 minutes. c) Tap water was added to the mixture and mixed for 2 to 3 minutes. Non-reinforced green mixes were prepared by the same steps mentioned above, except that the superplasticizer was mixed with tap water before adding into the mixture. Reinforced green mixes were prepared by the same steps mentioned above. Then, the fibers were added gradually in to the mixture.

At least three [3] specimens were cast for all mixes. These specimens were prepared at room temperature ($25 \pm 2^\circ\text{C}$). After 24 hour of molding and humidity not less than 75%, the specimens were demolded, immersed in tap water and treated up to 7 and 28 days.

Flow test was conducted for each mix according to ASTM C1437 [69]. Dry density test was conducted for $70.7 \times 70.7 \times 70.7$ mm specimens at 28 day according to ASTM C642 [70]. Ultrasonic pulse velocity (UPV) was performed through $70.7 \times 70.7 \times 70.7$ mm specimens at 28 day as per to ASTM C642 [70] after thirty minutes of taking them out of water. The compressive and flexural strength tests were applied on $50 \times 50 \times 50$ mm cubes and $40 \times 40 \times 160$ mm prisms at different ages (7 and 28 days) by using ASTM C109 [71] and ASTM C348 [72] respectively.

Motorized Cement flow table was used for measuring flowability of mixes. Laboratory oven was used to determine the mass of oven-dried sample and the mass of surface dry sample after boiling for 5 hours. Specific gravity apparatus was used to calculate apparent mass of the sample in water. Ultrasonic tester was utilized for measuring the propagation time of ultrasound pulses with a precision of $0.1 \mu\text{s}$ through $70.7 \times 70.7 \times 70.7$ mm specimen. Hydraulic compression testing machine (300 kN capacity) was utilized to measure compressive strength and flexural

strength for $50 \times 50 \times 50$ mm and $40 \times 40 \times 160$ mm samples, respectively, at age 7 and 28 days.

3.2 AHP and TOPSIS methodology

3.2.1 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision making approach which organizes and analyzes complex decisions [73]. It was developed by Thomas Saaty in the 1970, 1980 and 1990 [74]. The decision problem in this approach is arranged in hierarchic structure [74]. The arrangement is in the descending form from an overall goal to criteria, sub-criteria and alternatives in successive levels [75]. 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 non-reinforced green mortars. The criteria weight of reinforced green mortars and non-reinforced 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 Saaty [75] that is displayed in Table 7 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

Table 7: 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

Table 8: 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

(F) as shown below:

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

where f_{ij} represents a quantified judgment on C_i/C_j with $f_{ii} = 1$ and $f_{ij} = 1/f_{ji}$ for $i, j = 1, \dots, m$

Step 2:

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

$$x_{ij} = \frac{F_{ij}}{\sum_{i=1}^m F_{ij}} \quad (i = 1, 2 \dots 4, j = 1, 2 \dots 4) \quad (1)$$

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

Step 3:

Calculate the average of each row 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).

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

Where Y_{ij} represents the result of the multiplying f_{ij} by w_j , $i = 1, \dots, m$; $j = 1, \dots, m$.

- b) Calculate the sum of each row ($\sum_{j=1}^4 Y_{ij}$) in the matrix (Y). The result will be (S).

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

- c) Divide the calculated sum of each row (S) to criterion weight (w_i). The result will be (S/W)

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

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

$$CI = \frac{\left(\frac{\sum_{i=1}^m (S/w)_{ij}}{m} \right) - m}{m - 1} \quad (2)$$

(where, m is number of compared criteria)

The random consistency index (RCI) is obtained using Table 8. 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 [76].

3.3 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 [77]. 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 [62]. 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:

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

Where A_i represents the alternatives i , $i = 1, \dots, m$; C_j represents the criteria that are required on which the alternative is judged, $j = 1, \dots, n$; Z_{ij} represents j th attribute, $j = 1, \dots, n$ related to i , the alternative; and Z_{ij} is the obtained value representing the performance rating of each alternative A_i with respect to each requirement C_j .

Step 2:

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

$$V_{ij} = \frac{n_{ij}}{\sqrt{\sum_{i=1}^m n_{ij}^2}} \quad (3)$$

Where $i = 1, 2, 3, \dots, m$ and $j = 1, 2, 3, \dots, n$

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.

$$A^+ = \{a_1^+, a_2^+ \dots a_n^+\} = \{(\max_{j \in Cb} b_{ij}), (\min_{j \in Cp} b_{ij})\}$$

$$A^- = \{a_1^-, a_2^- \dots a_n^-\} = \{(\min_{j \in Cb} b_{ij}), (\max_{j \in Cp} b_{ij})\}$$

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

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

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

Step 6:

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

$$R_i = \frac{D_i^-}{(D_i^+) + (D_i^-)} \quad (6)$$

4 Results and discussion

4.0.1 Pozzolanic activity index (PAI)

The average of three values of compressive strength of mortar prepared for measuring the pozzolanic activity of waste glass powder, steel slag or silica fume are shown in (Figure 2). The ratio between compressive strength of mortar containing supplementary cementitious material (waste glass powder, steel slag or silica fume) and compressive strength of control mortar at the same age is called activity index which assesses the pozzolanic activity of the supplementary cementitious materials as displayed in (Figure 2). The results indicate that the compressive strength of mortar containing waste glass powder or steel slag decreases with increases cement. The reduction of the strength can be attributed to the reduction of the amount of cement and the pozzolanic activity variation of these materials and cement. Moreover, the presence of these materials in cement past lead to delay of C_3S and C_3A hydration at early age and the activity of the compounds ($SiO_2 + Al_2O_3 + Fe_2O_3$) of waste glass powder or steel slag is less than the activity of the same compounds of cement [23, 78].

Although, The use of waste glass powder and steel slag led to slightly decrease in the strength, these materials are considered in this study due to its pozzolanic activity. As per ASTM C 618 [79], the minimum requirement of strength

activity index for a standard pozzolana is 75% at age 7 and 28 days. Therefore, Waste glass powder and steel slag are considered as pozzolanic materials due to the strength activity index of waste glass powder and steel slag, at replacement level 20%, was 87 and 86% at age 7 days and 80 and 79% at age 28 days respectively.

Also, the strength activity index of silica fume was examined according to ASTM C1240 [80]. The results indicate that the strength activity index of silica fume, at replacement level 10%, is 112 and 104% at age 7 and 28 days respectively. As per ASTM C standard mentioned above, the minimum requirement of accelerated pozzolanic activity index of silica fume is 85% at age 7 days. Therefore, this material is considered as pozzolanic material in this research. Moreover, the results indicate that the compressive strength of mortar containing replacement ratio of cement by 10% of silica fume show the highest compressive strength in comparison with other mortars. Indeed, the high fineness, high content of amorphous silicon dioxide of silica fume and sufficient content of calcium hydroxide acquired by hydration of cement play a significant role on improvement production of calcium silicate hydrate (C-S-H) supplying additional compressive strength [19].

Figure 2: Activity index at 7 and 28 days

4.0.2 Workability

Table 9 exhibits the flowability of non-reinforced green mixes. This table indicates that the flowability of the mix decreases with increases the replacement ratio of cement by silica fume or/and steel slag. The high specific surface

of silica fume leads to more quantity demand of water for hydration and for flowability [21, 33, 81]. In contrast, waste glass powder content in mix does slightly increase of flow mix by increasing replacement ratio of cement. It might be the effect of glass material which is cleaner in nature. This result is supported by recently studies which conducted by other researchers [33, 82].

On the other side, the results in Table.10 indicate that the folwability of green mix reduces due to the addition of the sisal fibers. This can be attributed to the amount of cellulose which forms (43-56)% by weight of sisal fibers [83]. The large quantity of hydrophilic hydroxyl groups which containing cellulose make sisal fibers are water-absorbent [84]. The same trend at adding human hair fibers to the mix.

Indeed, the chemical composition of cortex and cuticle, which consisted of human hair fiber, rich of keratin peptide bonds as well as to hydrophilic side chains (phenolic, carboxyl, amino, hydroxyl, guanidine, etc.) which contribute to absorption of water [85]. Therefore, addition human hair fibers to the mix led to reduce its flowability. But, the inclusion of stainless steel nails in the mix increases the flowability of mortar as shown in Table 10. This is may be attributed to low porosity and softness of the surface of this type of fibers as well as shape of roller tapered of stainless steel nails.

In hybridization case, it is observed that the flowability of reinforced green mixes with hybrid fibers M10 and M11 was decreased obviously. Therefore, water-binder ratio was increased to 0.58 for obtaining flowability 80% and 60% for M10 and M11 respectively as shown in Table 10. The reduction of flowability of M11 was higher than M10. This can be attributed to the amount of sisal fibers and stainless steel nails which was used in the both mixes. The increment of sisal fiber volume fractions and reduction of stainless steel nails volume fraction in M11 led to decrease its flowability compared with M10.

4.0.3 Compressive strength

Table 9 lists the results of the compressive strength of non-reinforced green mortar. The results indicated that the compressive strength of mortars containing replacement ratio of cement by waste glass powder and steel slag was decreased in comparison with control mortar (U1) at 7 and 28 days. The decreasing rate was by 21.345, 0.778 and 9.895% at age 28 days for U2, U3 and U4, respectively. And by 22.937, 18.137 and 34.020% at age 28 days for U5, U6 and U7, respectively, in comparison with control mortar. So, the replacement 15% of cement by waste glass powder or steel

Table 9: Non-reinforced green mortar test results.

Mix Name	Cement mixes (%)	Flow (%)	Compressive strength (MPa)		Flexural strength (MPa)		UPV. (Km/sec)	Dry density (Kg/m ³)
			7day	28day	7day	28day	28day	28day
U1	100%OPC	113	36.465	40.331	6.821	7.823	4.521	2266
U2	90%OPC+10%WGP	113	26.691	31.722	6.012	6.782	4.046	2210
U3	85%OPC+15%WGP	115	33.879	40.017	6.681	7.800	4.402	2256
U4	80%OPC+20%WGP	109	30.373	36.340	6.594	7.497	4.287	2250
U5	90%OPC+10%SG	113	27.892	31.080	6.013	6.691	4.001	2212
U6	85%OPC+15%SG	110	29.608	33.016	6.303	7.142	4.131	2242
U7	80%OPC+20%SG	105	22.989	26.610	5.032	6.209	3.527	2165
U8	94%OPC+6%SF	105	36.948	42.836	6.701	7.482	4.556	2270
U9	92%OPC+8%SF	100	41.533	43.394	6.821	7.563	4.582	2283
U10	90%OPC+10%SF	82	43.372	48.866	7.021	8.032	4.713	2369
U11	80%OPC+8%WGP+12%SG	108	29.269	31.896	6.213	6.679	4.024	2220
U12	80%OPC+10%WGP+10%SG	115	28.059	33.927	5.861	7.380	4.356	2248
U13	80%OPC+5%WGP+15%SG	105	24.799	32.344	5.758	6.977	4.207	2229
U14	78%OPC+10%WGP+12%SG	110	26.887	31.908	5.823	6.782	4.092	2222
U15	75%OPC+12.5%WGP+12.5%SG	113	24.805	32.569	5.523	7.146	4.227	2235
U16	75%OPC+10%WGP+15%SG	109	23.271	30.331	5.227	6.094	4.032	2206
U17	74%OPC+8%WGP+12%SG+6%SF	113	23.204	29.323	5.321	6.502	3.901	2197
U18	72%OPC+8%WGP+12%SG+8%SF	110	25.178	30.088	5.921	6.821	4.021	2210
U19	70%OPC+8%WGP+12%SG+10%SF	108	29.572	32.068	6.221	7.321	4.107	2225

Table 10: Reinforced green mortar test results.

Index	Flow (%)	Compressive Strength (MPa)		Flexural Strength (MPa)		UPV. (Km/sec)	Dry density (Kg/m ³)
		7day	28-day	7-day	28-day	28-day	28-day
M0	135	20.480	28.088	4.452	4.831	3.645	2100
M1	128	20.661	28.206	4.686	5.166	3.667	2165
M2	118	21.657	30.170	4.968	5.562	3.919	2173
M3	105	20.773	28.265	4.858	5.202	3.668	2169
M4	132	20.547	29.021	4.621	5.021	3.887	2173
M5	128.6	20.809	30.733	4.829	5.342	3.989	2191
M6	126	20.490	28.675	4.612	5.088	3.701	2137
M7	138.6	21.677	29.012	6.092	6.285	3.901	2234
M8	142	21.930	29.597	6.560	6.767	3.951	2278
M9	144	22.912	32.408	7.005	8.177	3.991	2323
M10	80	23.555	28.578	5.661	5.787	3.698	2260
M11	60	22.130	28.098	5.295	5.638	3.655	2174

slag boosts the best performance in comparison with 10 and 20% replacement ratio of cement.

Moreover, the results of mortar using of the mixture of waste glass powder and steel slag as partial replacement of cement indicated that the compressive strength was reduced in comparison with control mortar at 7 and 28 days. The reduction was by 20.914, 15.878, 19.803, 20.884,

19.245 and 24.794% at age 28 days for U11, U12, U13, U14, U15 and U16, respectively. And, the reduction of compressive strength was by 27.294, 25.397 and 20.487% at age of 28 days for the mixes U17, U18 and U19, respectively, compared to control mortar.

The reduction of mortar strength containing waste glass powder or /and steel slag can be attributed to the de-

creasing of the amount of cement in the mix and the contribution of the hydration or the pozzolanic reactivity of waste glass powder or steel slag did not compensate for the reduction of the cement content [86]. Moreover, the presence of slag in cement mortar leads to slightly delay the hydration of C_3S at early age where slag acts as retarder to the hydration of compound C_3A [87].

Although, the results show that the presence of waste glass powder and steel slag led to decrease the strength, the reduction of the strength of mortar containing waste glass powder was lower than mortar containing slag. This is attributed to the high content of amorphous of silicon dioxide (72.71%) and the sufficient content of Na_2O in waste glass powder. Indeed, the presence of Na_2O in acceptable level led to act as a catalysts in forming calcium silicate hydrate in early age [78, 86].

While, the results of the mortar containing replacement ratio of cement by silica fume indicate that the compressive strength increases with increase silica fume content in the mortar compared with control mortar. The increments were by 6.211, 7.594 and 21.162% at age 28 days for U8, U9 and U10, respectively.

The increases in the compressive strength can be attributed to the decreased volume of large pores in the cement mortar and the spaces between fine aggregate and cement past due to its high fineness [63, 78]. Moreover, silica fume have significant role on the reducing of $Ca(OH)_2$ resulted from cement hydration by reacting with it to form $C_3S_2H_3$ [63, 78]. Thus, the presence of silica fume was enhanced the strength of mortar in this study.

On the other side, the drop in compressive strength of mortar containing silica fume, waste glass powder and steel slag blended cement can be attributed to the reasons mentioned above regarding to the presence of waste glass powder and steel slag. Although, the silica fume contributes to increase the strength of mortar the agglomeration of silica fume, which cannot be broken down by normal mixing, lead to decrease the strength. The core of agglomeration does not take part in hydration. Thus, it cause the weakness in binder paste [29].

Table 10 shows the results of reinforced green mortar with mono and hybrid fibers. This Table shows that the compressive strength of M1, M2 and M3 was increased by 0.420%, 7.412% and 0.630%, respectively, at age 28 days compared with control mortar M0. The higher increase was observed at M2 then the compressive strength of M3 was demonstrated the reductions by 4.081 and 6.314% at 7days and 28 days respectively. The increase in compressive strength may be attributed to identical SIF percent and bond strength between the surface of sisal fibers and com-

posites of mortar which led to diminish of porosity of hardened mortar [59].

While, reinforced mix by 0.5, 0.75 and 1% of human hair volume fractions led to increase the compressive strength of mortar by 3.321, 9.416 and 2.089% at 28 days respectively. This enhancement in compressive strength come back to the proper amount of HHF which did not lead to cause balling and lumping of HHF during the mixing process as well as high modulus, high tensile strength of HHF and its ability to reduce the micro-fractures or cracks of hardened mortar [54]. Also, it can be seen that the inclusion 1% of HHF in the mix led to decrease the compressive strength by 1.532 and 2.089% at age 7 and 28 days respectively in comparison with M5 as listed in Table 10. This reduction can be attributed to the agglomeration of HHF during blending with composites of mortar which has resulted in non-homogeneity mix as noted by [50].

Moreover, the results in Table 14, indicates that the compressive strength of M7, M8 and M9 increased by 3.290%, 5.372% and % 15.380, respectively at age 28 days in comparison with control mortar (M0). The increasing of compressive strength can be ascribed to the good mechanical bond strength between the stainless steel nails and mortar.

For hybrid fiber reinforced mortar, the compressive strength of M10 and M11 has shown increment by 1.744 and 0.035%, respectively, at age of 28 days, compared with control mortar.

4.0.4 Ultrasonic pulse velocity (UPV)

Table 9 illustrates the results of ultrasonic pulse velocity test (UPV) of non-reinforced green mortar. The results indicate that the UPV of mortar containing waste glass powder and steel slag was decreased compared to control mortar. The decreasing recorded rate ranged from 2.632 to 10.506% due to partial replacement of cement by WGP. Also, there were remarkable decreases of UPV due to the partial replacement of cement by SG. Such decreases ranged from 8.626 to 21.986% by such replacement. In contrast, the mortar containing replacement ratio of cement by the silica fume exhibited slight increases of UPV. The increasing rate ranged from 0.774 to and 4.246% by partial replacement of cement with SF. The grain size and high quantity of hydration products (C-S-H and CH) of silica fume in comparison with WGP and SG led to reduction in porosity and void ratio of hardened mortar [86]. Thus, UPV of mortar containing silica fume higher than UPV of mortar containing waste glass powder or/and steel slag.

The similar trend for mortar containing WGP, SG and SF blended cement. UPV results revealed mild to moderate decreases by the inclusions of different percentages of such cementitious materials.

However, the highest reduction of UPV has been obtained due to replacement of cement by to WGP and SG which has less efficiency compared with silica fume resulting in porosity and void ratio increases in the hardened mortar which cause decreasing in UPV [87].

The results in Table 10 indicate that the UPV of sisal fiber reinforced mortar, Human hair fiber reinforced mortar and stainless steel nail reinforced mortar showed higher values of UPV than that of control mortar. The increases in such values ranged from 0.603 to 9.492% for mixes (M1-M9). Moreover, the results of mortar containing hybrid fibers showed that the UPV of M10 and M11 increased by 1.454 and 0.274%, respectively, compared with control mortar. This can be attributed to good mechanical bond between the fibers and cementitious matrix and the ability of fibers to arrest cracks at the micro and macro levels which leads to densify of the microstructure and decrease the cracks and porosity in hardened mortar.

4.0.5 Flexural strength

The results of flexural strength of non-reinforced green mortar are given in Table 9. The results indicate that the flexural strengths of mortar containing waste glass powder or/and steel slag were decreased in comparison with control mortar (100%OPC). This can be attributed to the same reasons mentioned in compressive strength. However, a slight increase in flexural strength of mortar prepared by 90% OPC+10% SF has been recorded.

While, the results indicate that the flexural strength of mortar containing mono or hybrid fibers was higher than control mortar as listed in Table 10. The highest increases were 15.131, 10.577 and 69.261% at age 28days for individual fibers form 0.75% SIF, 0.75% HHF and 2% SNF. The developing of the flexural strength can be attributed to the good mechanical bond between the fibers and cementitious matrix. The presence of fibers, on the other hand, had a beneficial effect on the post-crack behavior, promote the flexural strength and ductility and hence toughness of the mortar [43]. The increasing of flexural strength was mainly observed in the reinforced mortar containing higher volume fraction of stainless steel nails due to the high elastic modulus of stainless steel nails compare to other fibers.

In hybridization case, It is observed that the flexural strength of M10 and M11 was higher than of control mortar. The increases were by 19.788 and 16.704% respec-

tively, at age 28 days. Moreover, the increment of the flexural strength of M9 was higher than that of M10 and M11. The increments were by 41.299 and 45.034% at age 28days, respectively. The use of mono stainless steel fibers shows a significant increment of flexural strength for mortar. While, the use of this type of the fiber with sisal fibers and human hair fibers in hybrid form led to decrease the flexural strength in comparison with mortar containing stainless steel nails in mono form. This can be attributed to clearly decrease the flowability of reinforced mortar with hybrid fibers. Besides of that, some of sisal fibers and human hair fibers were agglomerated leading to cause non-homogeneous mix.

4.0.6 Dry density

Table 9 depicts the results of oven dry density of non-reinforced green mortars. The obtained results indicate that the dry density of control mortar (100% OPC) was higher than mortar containing waste glass powder or/and steel slag. The decreasing of the density can be ascribed to the greater variation between pozzolanic reactivity of cement and supplementary cementitious materials (waste glass powder and steel slag) which led to increase the voids ratio and the porosity in hardened mortar. In contrast, the density of mortar containing silica fume. The results indicates that the density of mortar U8, U9 and U10 was higher than of control mortar (100%OPC). The increasing was by 0.176, 0.750 and 4.545% respectively. This is because of high amount of amorphous silicon dioxide made by silica fume to reduce Ca(OH)_2 provided by cement hydration to form calcium silicate hydrate gel [39, 54]. Moreover, the high fineness of silica fume made it acts as filler material and because of which fits the spaces between cement past matrix and the aggregate cement paste interfacial zone leading to improve the density of hardened mortar [20]. Also, it is observed that the dry density of M1, M2 and M3 was higher than Control mortar (M0). The increasing was by 3.095, 3.476 and 3.285% respectively as shown in Table 10. The same trend for M4, M5 and M6, there was little increasing by 3.476, 4.333 and 1.761% respectively. The reason can be attributed to good mechanical bond between cementitious matrix and fibers. Moreover, the use of sisal fibers and human hair fibers can contribute to fill the micro space in cementitious matrix leading to improve the density. Moreover, the inclusion of 1, 1.5 and 2% volumetric fraction of stainless steel nails led to increase the oven dry density. The increasing was by 6.380, 8.476 and 10.619% for M7, M8 and M9 in comparison with control mortar (M0). This is because of high specific gravity of stainless

steel nails and ability of this type of fibers to improve interfacial bond characteristics between the matrix and fibers.

For hybridization mixes, the results indicate that the dry density of M10 and M11 was increased by 7.619 and 3.523, respectively, in comparison with control mortar (M0). These enhancements are attributed to appropriate ratio uses of sisal fiber, human fiber and stainless steel nails volume fraction which led to improve the microstructure of matrix [48, 54].

4.1 Estimation of green mortar cost

The estimated cost of reinforced green mortar was evaluated on the basis of the different materials which were used to prepare green mortar as listed in Table 11-12. The estimated cost of each material was depended on the existing market cost.

Table 11: Estimated cost of material used

Materials	Quantity	Cost in USD (\$)
OPC	1000 Kg	67\$
WGP	1000 Kg	55\$ ¹
SG	1000 Kg	55\$ ¹
SF	1000 Kg	850\$
Local River Sand	1000 Kg	17\$
Superplasticizer	1000 Liter	1000\$
SIF	1000 Kg	150\$
HHF	1000 Kg	100\$ ²
SNF	1000 Kg	800\$

1: Grinding cost, 2: Collecting and Washing cost

4.2 Selection of the best green mortar

The integrated AHP and TOPSIS method was also used to rank and select the best reinforced green mortar. In this stage, there were twelve [12] alternatives and four [4] criteria of reinforced green mortars. The alternatives were represented the reinforced green mortars. The criteria were represented the properties of the reinforced green mortar which were Compressive strength, Flexural strength, UPV and Cost. Based on AHP method, the weight for each criterion was calculated. The matrices and results, which were obtained through applying of AHP method to evaluate the criterion weight, were illustrated in Table 13-14. The checking of pair-wise matrix (F) was achieved according to the step 4 which was previously mentioned in the general steps of AHP method. The results were listed in Table 15. The consistency index (CI) obtained was 0.020 and the random consistency obtained from Table 8 was 0.9. Thus, the pair-wise comparison matrix was considered in this study due to the consistency ratio was 0.022. Then, TOPSIS

Table 13: The pair-wise comparison matrix (F) of reinforced green mortars (AHP method).

	Compressive strength	Flexural strength	UPV	Cost in USD
Compressive strength	1	1	2	1/3
Flexural strength	1	1	2	1/3
UPV	1/2	1/2	1	1/3
Cost in USD	3	3	3	1

Table 12: Estimated cost of reinforced green mortar

Index	OPC (Kg/m ³)	Sand (Kg/m ³)	WGP (Kg/m ³)	SG (Kg/m ³)	SF (Kg/m ³)	SIF (Kg/m ³)	HHF (Kg/m ³)	SNF (Kg/m ³)	Sp. (L/m ³)	Cost in USD
M0	358	1405	41	61	51	-	-	-	10	106.831
M1	358	1405	41	61	51	7	-	-	10	107.881
M2	358	1405	41	61	51	10.5	-	-	10	108.406
M3	358	1405	41	61	51	14	-	-	10	108.931
M4	358	1405	41	61	51	-	2	-	10	107.031
M5	358	1405	41	61	51	-	3	-	10	107.131
M6	358	1405	41	61	51	-	4	-	10	107.231
M7	358	1405	41	61	51	-	-	66.8	10	160.271
M8	358	1405	41	61	51	-	-	100	10	186.831
M9	358	1405	41	61	51	-	-	134.6	10	214.511
M10	358	1405	41	61	51	7	2	100	10	188.081
M11	358	1405	41	61	51	10.5	2	66.8	10	162.046

Table 14: Matrix X calculated and weights of criteria of reinforced green mortars (AHP method).

	Compressive strength	Flexural strength	UPV	Cost in USD
Compressive strength	0.181818	0.181818	0.25	0.166667
Flexural strength	0.181818	0.181818	0.25	0.166667
UPV	0.090909	0.090909	0.195076	0.118371
Cost in USD	0.545455	0.545455	0.375	0.5
Weight	0.195076	0.195076	0.118371	0.491478

Table 15: Matrix Y for checking the pair-wise comparison matrix evaluated in AHP method.

	Compressive strength	Flexural strength	UPV	Cost in USD	S_i	S_i/w_i
Compressive strength	0.195076	0.195076	0.236742	0.163826	0.79072	4.053395
Flexural strength	0.195076	0.195076	0.236742	0.163826	0.79072	4.053395
UPV	0.097538	0.097538	0.118371	0.163826	0.477273	4.03201
Cost in USD	0.585228	0.585228	0.355113	0.491478	2.017047	4.104043

Table 16: The alternatives and criteria used in TOPSIS method for ranking of reinforced green mortars.

Index	Compressive Strength (MPa)	Flexural Strength (MPa)	UPV (Km/sec)	Cost in USD
	28 days	28 days	28 days	
A1	28.206	5.166	3.667	107.881
A2	30.170	5.562	3.919	108.406
A3	28.265	5.202	3.668	108.931
A4	29.021	5.021	3.887	107.031
A5	30.733	5.342	3.989	107.131
A6	28.675	5.088	3.701	107.231
A7	29.012	6.285	3.901	160.271
A8	29.597	6.767	3.951	186.831
A9	32.408	8.177	3.991	214.511
A10	28.578	5.787	3.698	188.081
A11	28.098	5.638	3.655	162.046

Table 17: Normalized decision matrix (V) obtained from TOPSIS method for reinforced green mortars.

	Compressive strength	Flexural strength	UPV	Cost in USD
A ₁	0.289572	0.264401	0.289208	0.221168
A ₂	0.309736	0.284669	0.309083	0.222244
A ₃	0.290178	0.266244	0.289287	0.22332
A ₄	0.29794	0.25698	0.306559	0.219425
A ₅	0.315515	0.273409	0.314604	0.21963
A ₆	0.294387	0.260409	0.29189	0.219835
A ₇	0.297847	0.321673	0.307663	0.328573
A ₈	0.303853	0.346342	0.311607	0.383024
A ₉	0.332712	0.418507	0.314761	0.439771
A ₁₀	0.293392	0.296185	0.291653	0.385587
A ₁₁	0.288464	0.288559	0.288262	0.332212

Table 18: The weight normalized decision matrix (B) and the positive and negative ideal reference point obtained from TOPSIS method.

	Compressive strength	Flexural strength	UPV	Cost in USD
A_1	0.056489	0.051578	0.034234	0.108699
A_2	0.060422	0.055532	0.036586	0.109228
A_3	0.056607	0.051938	0.034243	0.109757
A_4	0.058121	0.050131	0.036288	0.107842
A_5	0.061549	0.053336	0.03724	0.107943
A_6	0.057428	0.0508	0.034551	0.108044
A_7	0.058103	0.062751	0.036418	0.161486
A_8	0.059274	0.067563	0.036885	0.188247
A_9	0.064904	0.081641	0.037259	0.216137
A_{10}	0.057234	0.057779	0.034523	0.189507
A_{11}	0.056272	0.056291	0.034122	0.163275
a_i^+	0.064904	0.081641	0.037259	0.107842
a_i^-	0.056272	0.050131	0.034122	0.216137

Table 19: The distance to the positive and negative ideal reference point (Di^+ and Di^-), Relative closeness coefficient (R_i) to the ideal reference point and the ranking for each alternative.

Number of mix	Alternative	Di^+	Di^-	R_i	Ranking of the alternative
1	A_1	0.031376	0.107448	0.773987	4
2	A_2	0.026535	0.107155	0.801518	1
3	A_3	0.031046	0.106396	0.774116	3
4	A_4	0.032247	0.108332	0.770613	6
5	A_5	0.028503	0.108415	0.791824	2
6	A_6	0.03185	0.108102	0.772422	5
7	A_7	0.057284	0.056166	0.495073	7
8	A_8	0.081823	0.033142	0.288279	9
9	A_9	0.108295	0.032821	0.232582	11
10	A_{10}	0.085468	0.027726	0.244942	10
11	A_{11}	0.061642	0.05322	0.463339	8

method was applied to rank the reinforced green mortars. The raw data used in the TOPSIS technique, were listed in Table 16. The matrices and the results obtained from this technique were show in Table 17-18. Table 19 showed that the second mix of the reinforced green mortar is the best as it got the rank 1 and the ninth mix is the worst mix as it got the rank 11.

5 Conclusions

Some conclusions are revealed for this study which deals with the production of green mortar as follows:

1. Replacement of OPC by 10, 15 and 20% of WGP or SG with or without using superplasticizer leads to decrease the compressive strength of mortar. The replacement ratio of 15% from WGP shows the best performance of mortar compared with another replacement ratio. Thus, the percentage of compressive strength decrease is 0.778% compared with control mortar mix.
2. Incorporation of 10% SF as replacement of OPC with or without utilizing superplasticizer, gives the highest increase in the compressive strength strength by about 21% compared to control mix. Also the UPV and density for such mortar mix shows increases from 4.512 to 4.713 Km/sec and 2226 to 2369 Kg/m³ compared to control mortar mix.
3. Inclusion of mono fibers into the green mortar shows significant increases in flexural strength compared with control mortar. Using mono sisal fiber, human hair fiber and stainless nails fiber by 0.75, 0.75 and 2% of volume fraction, respectively, gives

the highest increases compared with control mortar in compressive strength, by about 7.4, 9.4 and 15.4%, respectively. And in flexural strengths are increased by about 15.1, 10.6 and 69.3%, respectively. UPV values are increased by 3.47, 4.33 and 10.6%, respectively.

4. The hybridization of sisal fibers, human hair fibers and stainless steel fibers gives remarkable increases in the compressive strength, flexural strength and UPV compared with control mortar. The highest increases of compressive strength, flexural strength and UPV are 1.7, 19.7 and 1.45, respectively, for the mortar mix with 0.5% SIF + 0.5% HHF + 1.5% SNF compared with control mortar mix.
5. The use of integrated AHP and TOPSIS method shows good strategy for the selection of best mortar mixes whether they are reinforced or non-reinforced green mortar. Such methods help the researchers for selecting the best green mortars which are economic and ecofriendly mortars that possess positive impacts on the environment.

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References

- [1] IEA. Cement-Tracking Industry. IEA, Paris. 2019. Available from: <https://www.iea.org/reports/tracking-industry-2019>.
- [2] Valderrama C, Granados R, Luis J, Gasol CM, Guillem M, Josa A. Implementation of best available techniques in cement manufacturing: a life-cycle assessment study. *J Clean Prod* [Internet]. 2012;25:60–7. Available from: <http://dx.doi.org/10.1016/j.jclepro.2011.11.055>
- [3] Jose-Luis Galvez-Martosa HS. Resources, Conservation and Recycling An analysis of the use of life cycle assessment for waste co-incineration in cement kilns. *Resources, Conserv Recycl* [Internet]. 2014;86(x):118–31. Available from: <http://dx.doi.org/10.1016/j.resconrec.2014.02.009>
- [4] Simge Çankaya BP. A comparative life cycle assessment for sustainable cement production in Turkey. *J Environ Manage* [Internet]. 2019;249:1–11. Available from: <https://doi.org/10.1016/j.jenvman.2019.109362>
- [5] Ernst Worrell, Katerina Kermeli CG. Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making. *ENERGY STAR® Guid Energy Plant Manag*. 2013.
- [6] Shraddha Mishra DNAS, Health. A Review On Environmental and Health Impacts Of Cement Manufacturing Emissions. *Int J Geol Agric Environ Sci*. 2014;2(3):26–31.
- [7] K.Syamala Devi VVL and AA. Impacts of Cement Industry on Environment – An Overview. *Asia Pacific J Res*. 2018;1:156–61.
- [8] Andrew, Robbie M. Global CO₂ Emissions from Cement Production. *Earth System Science Data*. 2018;10, 195–217. Available from: <https://doi.org/10.5194/essd-10-195-2018>
- [9] DAN BABOR DP and LJ, Abstract. Environmental Impact of Concrete. *Bull Polytech Inst Jassy, Constr Archit Sect*. 2009;4(59):27–35.
- [10] Ali N, Jaffar A, Anwer M, Alwi SKK, Anjum MN, Ali N, Raja MR, Hussain A, Meng X. The Greenhouse Gas Emissions Produced by Cement Production and Its Impact on Environment: A Review of Global Cement Processing. *Int J Res (IJR)*. 2015;2(2):489–500.
- [11] Roskill Information Services. Outlook for silicon metal diverges sharply from that for ferrosilicon. Roskill, united kingdom. 2017. Available from: <https://roskill.com/news/outlook-silicon-metal-diverges-sharply-ferrosilicon>
- [12] Malhotra K. Iron and Steel Slag Utilization: A Comprehensive Analysis. *Int J Eng Sci Invent*. 2019;8(08):69–75.
- [13] Dave N, Kumar A, Srivastava A, Kumar S. Experimental analysis of strength and durability properties of quaternary cement binder and mortar. *Constr Build Mater* [Internet]. 2016;107:117–24. Available from: <http://dx.doi.org/10.1016/j.conbuildmat.2015.12.195>
- [14] Alwared A, Al-Hubboubi S, Rasen RA. Effect of Waste Glass Powder as a Supplementary Cementitious Material on the Concrete Mix Properties. *Assoc Arab Univ J Eng Sci*. 2018;25(4):43–54. Available from: <https://doi.org/10.13140/RG.2.2.21896.67845>
- [15] Islam MM, Islam MS, Rahman MA DA. STRENGTH BEHAVIOR OF MORTAR USING SLAG AS PARTIAL REPLACEMENT OF CEMENT. *MIST Journal: GALAXY(DHAKA)*. 2011; 1–10. Available from: <https://doi.org/10.3329/mist.v3i0.8053>
- [16] Khazaleh, Mahmoud. Eco-Friendly Green Concrete: A Review. *IAPE '19*, Oxford, United Kingdom: 19–21. 2019.
- [17] Muthupriya, P, B G Vishnuram, and K Subramanian. PREVENTION OF AIR POLLUTION BY USING SILICA FUME AS CEMENTITIOUS MATERIAL. *Nature Environment and Pollution Technology*. 2008; 7 (2): 267–70.
- [18] Abbas S, Soliman AM, Nehdi ML. Exploring mechanical and durability properties of ultra-high performance concrete incorporating various steel fiber lengths and dosages. *Constr Build Mater* [Internet]. 2015;75:429–41. Available from: <http://dx.doi.org/10.1016/j.conbuildmat.2014.11.017>
- [19] Mehta A, Ashish DK. Silica fume and waste glass in cement concrete production: A review. *J Build Eng* [Internet]. 2019;100888. Available from: <https://doi.org/10.1016/j.job.2019.100888>
- [20] Ramli CCB and M. Mechanical Strength and Durability Properties of High Performance Mortar Containing Densified Silica Fume. *Am J Appl Sci*. 2011;8(1):82–91. Available from: <https://doi.org/10.3844/ajassp.2011.82.91>
- [21] Rashad AM. Recycled waste glass as fine aggregate replacement in cementitious materials based on Portland cement. *Constr Build Mater* [Internet]. 2014;72:340–57. Available from: <http://dx.doi.org/10.1016/j.conbuildmat.2014.08.092>
- [22] Afroz M, Venkatesan S, Patnaikuni I. Effects of hybrid fibers on the development of high volume fly ash cement composite. *Constr Build Mater* [Internet]. 2019;215:984–97. Available from: <https://doi.org/10.1016/j.conbuildmat.2019.04.083>
- [23] Shao Y, Lefort T, Moras S, Rodriguez D. Studies on concrete containing ground waste glass. *Cem Concr Res*. 2000;30:91–100.
- [24] Caijun Shi KZ. A review on the use of waste glasses in the production of cement and concrete. *Resour Conserv Recycl*. 2007;52:234–47. Available from: <https://doi.org/10.1016/j.res>

- conrec.2007.01.013
- [25] Bignozzi MC, Sacconi A, Barbieri L, Lancellotti I. Glass waste as supplementary cementing materials: The effects of glass chemical composition. *Cem Concr Compos J* [Internet]. 2015;55:45–52. Available from: <http://dx.doi.org/10.1016/j.cemconcomp.2014.07.020>
 - [26] Kamali M, Ghahremaninezhad A. An investigation into the hydration and microstructure of cement pastes modified with glass powders. *Constr Build Mater* [Internet]. 2016;112:915–24. Available from: <http://dx.doi.org/10.1016/j.conbuildmat.2016.02.085>
 - [27] Demirboga R. Thermal conductivity and compressive strength of concrete incorporation with mineral admixtures. *Build Environ*. 2007;42:2467–71. Available from: <https://doi.org/10.1016/j.buildenv.2006.06.010>
 - [28] Dubey S, Singh A, Kushwah SS. Utilization of iron and steel slag in building construction. *AIP Conf Proc* 2158. 2019;020032:1–6. Available from: <https://doi.org/10.1063/1.5127156>
 - [29] Zhang Z, Zhang B, Yan P. Comparative study of effect of raw and densified silica fume in the paste, mortar and concrete. *Constr Build Mater* [Internet]. 2016;105:82–93. Available from: <http://dx.doi.org/10.1016/j.conbuildmat.2015.12.045>
 - [30] Huang Cheng-yi and R.F. Feldman. Influence of Silica Fume on the Microstructural Development in Cement Mortars. *Cement and Concrete Research*.1985;15(2): 285–94. Available from: [https://doi.org/10.1016/0008-8846\(85\)90040-7](https://doi.org/10.1016/0008-8846(85)90040-7)
 - [31] Imam A, Kumar V, Srivastava V. Review study towards effect of Silica Fume on the fresh and hardened properties of concrete. *Adv Concr Constr*. 2018;6(2):145–57.
 - [32] Merzoud ZD and M. Effect of Slag and Natural Pozzolan on the Mechanical Behavior of Recycled Glass Mortars [Internet]. Springer International Publishing; 2019. 63–75 p. Available from: <http://link.springer.com/10.1007/978-3-030-11827-3>
 - [33] Rao, G Appa. Investigations on the performance of silica fume-incorporated cement pastes and mortars. *Cem Concr Res*. 2003;33(11):1765–70. Available from: [https://doi.org/10.1016/S0008-8846\(03\)00171-6](https://doi.org/10.1016/S0008-8846(03)00171-6)
 - [34] Singh H, Bansal S. EFFECT OF SILICA FUME ON THE STRENGTH OF CEMENT MORTAR. *IJRET Int J Res Eng Technol*. 2015;4(2):623–7.
 - [35] Chouhan, Prabhulal, Sagar Jamle, and M P Verma. Effect of Silica Fume on Strength Parameters Of Concrete As A Partial Substitution of Cement. *IJSART3*. 2017;(5): 3-7.
 - [36] Khan MI. 14. Nanosilica/silica fume [Internet]. *Waste and Supplementary Cementitious Materials in Concrete*. Elsevier Ltd; 2018. 461–491 p. Available from: <http://dx.doi.org/10.1016/B978-0-08-102156-9.00014-6>
 - [37] Abdul Ghayoor Khan BK. Effect of Partial Replacement of Cement by Mixture of Glass Powder and Silica Fume Upon Concrete Strength. *Int J Eng Work Kam-bohwell Publ Enterp*. 2017;4(7):124–35.
 - [38] Liu, Jin, and Dongmin Wang. Influence of steel slag-silica fume composite mineral admixture on the properties of concrete. *Powder Technology*. 2017; 320: 230–38. Available from: <https://doi.org/10.1016/j.powtec.2017.07.052>
 - [39] Neville, AM. *Properties of Concrete*, 2nd edition. Longman Limited.1995.
 - [40] O.S. Abiola. 8 - Natural fibre cement composites [Internet]. *Advanced High Strength Natural Fibre Composites in Construction*. Elsevier Ltd; 2017. 205–214 p. Available from: <http://dx.doi.org/10.1016/B978-0-08-100411-1.00008-X>
 - [41] Kadhum MM. Studying of Some Mechanical Properties of Reactive Powder Concrete Using Local Materials. 2015;21(7).
 - [42] N.Pannirselvam, K.Chandra mouli, D.V.V.NagaSaiPardhu VA. Experimental Investigation on Special Concrete Using Steel Nail. *Int J Recent Technol Eng*. 2019;7(6S):835–6.
 - [43] Fujiyama R, Darwish F, Pereira M V. Mechanical characterization of sisal reinforced cement mortar. *Chinese Soc Theor Appl Mech Lett*. 2014;061002:1–5.
 - [44] Badagha DG, Modhera CD. Studies On Harden Properties Of Mortar Using Steel Fibre. *Int J Eng Res Technol*. 2013;2(6):42–6.
 - [45] Mahzabin Afroz , Srikanth Venkatesan IP. Effects of hybrid fibers on the development of high volume fly ash cement composite. *Constr Build Mater* [Internet]. 2019;215:984–97. Available from: <https://doi.org/10.1016/j.conbuildmat.2019.04.083>
 - [46] Verma IS and D. Construction Materials Reinforced with Natural Products. Springer Nat Switz AG 2019 L M T Martínez al (eds), *Handb of Ecomaterials*. 2019;2119–42.
 - [47] MUGURE WN. INVESTIGATION OF THE PERFORMANCE OF NATURAL FIBRES AS A MICRO REINFORCEMENT IN CONCRETE. *Univ NAIROBI Investig*. 2009.
 - [48] Okeola AA, Mwero SOA and J. Experimental Investigation of the Physical and Mechanical Properties of Sisal Fiber-Reinforced Concrete. *Fibers*. 2018.
 - [49] Raylane de Souza Castoldi, Lourdes Maria Silva de Souza F de AS. Comparative study on the mechanical behavior and durability of polypropylene and sisal fiber reinforced concretes. *Constr Build Mater* [Internet]. 2019;211:617–28. Available from: <https://doi.org/10.1016/j.conbuildmat.2019.03.282>
 - [50] T.Naveen Kumar, Komershetty Goutami, Jinna Aditya, Kuppala Kavya, V.Raja Mahendar DRCR and S kaushik. An Experimental Study on Mechanical Properties of Human Hair Fibre Reinforced Concrete (M-40 Grade). 2015;12(4):65–75.
 - [51] Narain Das Bheel, Sohail Ahmed Abbasi, Shanker Lal Meghwar FAS. Effect of Human hair as Fibers in Cement Concrete. *Int Conf Sustain Dev Civ Eng*. 2017;0–6.
 - [52] Pavankumar, S. An Experimental Investigation on Human Hair Fibre Concrete. *International Journal of Innovative Research in Science, Engineering and Technology(IJIRSET)*. 2017;6(1):435–42. Available from: <https://doi.org/10.15680/IJIRSET.2017.0601080>.
 - [53] Manivel S, Assistant. EXPERIMENTAL STUDY ON HUMAN HAIR FIBER REINFORCED CONCRETE WITH PARTIAL REPLACEMENT OF CEMENT BY GGBFS. *Int J Civ Eng Technol*. 2017;8(4):1145–55.
 - [54] Singh MO and GD. An Experimental Investigation on Hair Fibre as Fibre Reinforcement in Concrete Mohammad. *Asian J Curr Eng Maths* 85. 2019;1–8.
 - [55] Nila V. M, Raijan K.J, Susmitha Antony, Riya Babu M NRD. Hair Fibre Reinforced Concrete. *Int Conf Technol Adv Struct Constr*. 2015;60–7.
 - [56] Sakshi Gupta AS. HUMAN HAIR AS FIBRE MATERIAL IN REINFORCED CONCRETE. *Int Conf Adv Constr Mater Struct*. 2018.
 - [57] Dias, Romildo, Toledo Filho, Kuruvilla Joseph, Khosrow Ghavami, and George L England. The use of sisal fibre as reinforcement in cement based composites. *Revista Brasileira de Engenharia Agrícola e Ambiental*. 1999;3(2):245–256. Available from: <https://doi.org/10.1590/1807-1929/agriambi.v3n2p245-256>
 - [58] Dawood ET, Mahyuddin R. High strength characteristics of cement mortar reinforced with hybrid fibres. *Constr Build Mater* [Internet]. 2011;25(5):2240–7. Available from: <http://dx.doi.org/10.1016/j.conbuildmat.2010.11.008>

- [59] Ramakrishna, G, and T Sundararajan. 10-Long-term strength and durability evaluation of sisal fiber composites. *Durability and Life Prediction in Biocomposites, Fibre-Reinforced Composites and Hybrid Composites*. Elsevier Ltd.2019. Available from: <https://doi.org/10.1016/B978-0-08-102290-0.00010-6>
- [60] S. Janani ASS. Multiple Linear Regression Model for Mechanical Properties and Impact Resistance of Concrete with Fly Ash and Hooked-end Steel Fibers. *Int J Technol*. 2018;3:526–36.
- [61] Kiambigi, Maina, Gwaya, A.O, Koteng D. Concrete Strength Prediction using Multi-Linear Regression Model: A case study of Nairobi Metropolitan. *Int J Soft Comput Eng*. 2019;8(5):11–20.
- [62] P.S. Song SH. Mechanical properties of high-strength steel fiber-reinforced concrete. *Constr Build Mater*. 2004;18:669–73.
- [63] Atici U. Prediction of the strength of mineral admixture concrete using multivariable regression analysis and an artificial neural network. *Expert Syst Appl [Internet]*. 2011;38(8):9609–18. Available from: <http://dx.doi.org/10.1016/j.eswa.2011.01.156>
- [64] Mojtaba Tabatabaeian, Alireza Khaloo, Alireza Joshaghani EH. Experimental investigation on effects of hybrid fibers on rheological, mechanical, and durability properties of high-strength SCC. *Constr Build Mater [Internet]*. 2017;147:497–509. Available from: <http://dx.doi.org/10.1016/j.conbuildmat.2017.04.181>
- [65] ASTM C188. Standard Test Method for Density of Hydraulic Cement . Annual book of ASTM Standards. 2016.
- [66] ASTM C204. Standard Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus. Annual book of ASTM Standards. 2011.
- [67] ASTM C778. Standard Specification for Standard Sand. Annual book of ASTM Standards. 2013.
- [68] ASTM C1437. Standard Test Method for Flow of Hydraulic Cement Mortar. Annual book of ASTM Standards. 2013.
- [69] ASTM C128. Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate. Annual book of ASTM Standards. 2015.
- [70] ASTM C642 (2013). Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. Annual book of ASTM Standards. 2013.
- [71] ASTM C109. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens). Annual book of ASTM Standards. 2013.
- [72] ASTM C348 (2014). Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars. Annual book of ASTM Standards. 2014.
- [73] Aseel B. AL-Zubaid , Kadum Muttar Shabeeb AIA. Study The Effect of Recycled Glass on The Mechanical Properties of Green Concrete. *Energy Procedia [Internet]*. 2017;119:680–92. Available from: <http://dx.doi.org/10.1016/j.egypro.2017.07.095>
- [74] Wendell de Queiroz Lamas, Jose Carlos Fortes Palau JR de C. Waste materials co-processing in cement industry: Ecological efficiency of waste reuse. *Renew Sustain Energy Rev [Internet]*. 2013;19:200–7. Available from: <http://dx.doi.org/10.1016/j.rser.2012.11.015>
- [75] Saaty, Thomas L. How to Make a Decision: The Analytic Hierarchy Process” *European Journal of Operational Research*. 1990;48:9-26.
- [76] Michael Taylor CT and DG. Energy Efficiency and CO₂ Emissions from the Global Cement Industry. 2006.
- [77] World Bank. Trends in Solid Waste Management. The World Bank Group. 2019. Available from: <http://datatopics.worldbank.org/what-awaste/trendsinsolidwastemanagement.html>.
- [78] Ruben Snellings GM and JE. Supplementary Cementitious Materials. *Rev Mineral Geochemistry*. 2012;74(Blezard 2001):211–78.
- [79] ASTM C618. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. Annual book of ASTM Standards. 2012a.
- [80] ASTM C1240. Standard Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout. Annual book of ASTM Standards. 2000.
- [81] S. L. Fávaro, T. A. Ganzerli, A. G. V. de Carvalho Neto, O. R. R. F. da Silva ER. Chemical , morphological and mechanical analysis of sisal fiber-reinforced recycled high- Density polyethylene composite. *eXPRESS Polym Lett*. 2010;4(8):465–73.
- [82] Li, Y., & Shen, Y. O. The use of sisal and henequen fibres as reinforcements in composites. *Biofiber Reinforcements in Composite Materials*. 2015;165-210. Available from: <https://doi.org/10.1533/9781782421276.2.165>
- [83] Robbins, Clarence R. Chemical and Physical Behavior of Human Hair. Weitere Fachgebiete > Medizin > Klinische Und Innere Medizin > Dermatologie Schnell Und Portofrei Erhältlich Bei Chemical Composition of Different Hair Types. 2012. <https://doi.org/10.1007/978-3-642-25611-0>.
- [84] Bazhuni MF, Kamali M, Ghahremaninezhad A. An investigation into the properties of ternary and binary cement pastes containing glass powder. *Front Struct Civ Eng*. 2018;1–10. <https://doi.org/10.1007/s11709-018-0511-5>.
- [85] Hogan, F. J. and Meusel, J. W. Evaluation for durability and strength development of a ground granulated blast furnace slag. *Cement, Concrete and Aggregates, CCAGDP*. 1981;3(1): 40-52.
- [86] Lafhaj Z, Goueygou M, Djerbi A, Kaczmarek M. Correlation between porosity , permeability and ultrasonic parameters of mortar with variable water / cement ratio and water content. *Cem Concr Res*. 2006;36:625–33. Available from: <https://doi.org/10.1016/j.cemconres.2005.11.009>.
- [87] Yılmaz T, Ercikdi B, Karaman K, Külekçi G. Assessment of strength properties of cemented paste backfill by ultrasonic pulse velocity test. *Ultrasonics [Internet]*. 2014; Available from: <http://dx.doi.org/10.1016/j.ultras.2014.02.012>