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ORIGINAL ARTICLE

Creating a new type of concrete by using waste electrical cable plastic and waste electrical cable rubber: as a sustainable approach

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Abstract: Solid waste is among the World's most critical environmental issues. One of the most significant shares of total solid waste is occupied by electronic waste. One way to reduce waste is to use it as an aggregate in Sustainable Concrete (SC). However, there is little research on using waste electrical cable rubber (WECR) or Waste Electrical Cable plastic (WECP) in concrete, unlike waste tire rubber and plastic in concrete, which have attracted much attention among researchers. Research was conducted by substituting waste electrical cable - plastic sand (WEC-PS) instead of natural sand, and Waste Electrical Cable -Rubber Filler (WEC-RF), as an addition in concrete, accounted for 5%, 10%, 15%, and 20% respectively for both. Researched compressive strength, flexural strength, splitting strength, modulus of elasticity, and unit weight of concrete. Experimental studies revealed that replacing natural sands with WEC-PS increases strength by 18.10%. It seems obvious that replacing natural sands with WEC-PS up to 15% or adding WEC-RF up to 5% increases the mechanical properties of concrete. However, the situation changes when using in large ratios.

Keywords: Waste Electrical Cable- plastic sand (WEC-PS), Waste Electrical Cable- Rubber Filler (WEC-RF), Natural Sand (NS), Lightweight Concrete (LC), Sustainable Concrete (SC).

1 Introduction

Solid waste is a significant environmental problem worldwide. For example, the consumption of plastic solid waste constitutes a large proportion of the total solid waste generated [1, 2]. The world's consumption of plastic has increased to approximately 300 million tons in the last 65 years from just 5 million tons annually. Sustainable construction should identify ways to recycle waste and minimize energy consumption, pollution, and waste [3, 4]. The industry should also prioritize reducing the Use of primary building materials by increasing the proportion of recycled materials. The Use of everyday items such as rubber tires and plastics is rising yearly. Much research is devoted to using polymeric wastes like plastic aggregates and oil palm shells. Including plastic particles alters regular cement concrete properties [5, 6]. Recycled plastics decrease the general mass density in addition to the compressive strength, tensile-splitting strength, and abrasion resistance of typical concrete. The more the content of plastic aggregates in the concrete mixtures, the less their characteristics become [7, 8]. Similarly, a small amount of plastic aggregates added initially reduced water absorption in cement, though larger amounts also increased this factor. No significant decrease was observed after reducing small volumes of plastic aggregates in cement [9, 10]. The more plastic aggregates mixed with cement

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paste for concretes, the higher the abrasion resistance rates and sound insulation properties, while the lower the thermal conductivity level [11-13]. Plastic material can be recycled, but it is not easy for nature to destroy it. One method that can prevent that is using them as aggregate, fiber, or part of a cement binder for materials based on cement [11, 14, 15].

On the other hand, numerous studies have been conducted on recycling rubber into concrete, and most are about rubberized concrete (RAC). However, not much research has been done on recycling waste electrical cable rubber (WECR) in concrete despite many studies about waste tire rubber [16, 17]. Various studies appear contradictory regarding the feasibility of rubber-aggregate concrete, but they are logical explanations. Rubber aggregates have sharp corners compared to plain concrete; on the other hand, in some research, increased rubber aggregates led to higher slump levels due to the shape or hydrophobic structure of specific plastic aggregates utilized, or even reducing cohesion through diminishing adherence in the mortar paste [18, 19]. As anticipated, the lightness of the rubber materials inside it has gradually made the aggregated concrete lighter. The water absorption ratio for concrete varies depending on the kind of rubber aggregates. Also, increased rubber aggregate quantity can cause more water absorption into concrete. Rubber aggregates added to concrete result in significant losses of strength. The researchers have revealed that approximately 50% of the original strength can be lost, depending on the extent of replacing coarse aggregate with rubber aggregate [20, 21]. The compressive strength is 85%, the splitting tensile strength is 50% of control, and the fine aggregate is completely replaced by rubber aggregate. It also indicated a remarkable drop in compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity occurs when the water-to-cement ratio increases from 0.55 to 0.60 [22, 23]. Rubber aggregates increase porosity, which decreases ultrasonic pulse velocity (UPV) significantly in concrete. Studies have shown a relationship between rubber aggregate content and abrasion resistance in concrete, where it is reduced accordingly [24-26].

New concrete was made containing two recycled (using waste electrical cable plastic and waste electrical cable rubber). In this study, concrete was integrated with concrete waste in concrete to examine one more possible idea in the sustainable construction domain. Most waste originates from manufacturing and cable companies. This study utilizes the waste to produce lightweight aggregate concrete. More specifically, this research investigated the concrete's mechanical properties, focusing on a rubber-type waste. Their significance as sustainable materials and the pollution potential of aggregate use in concrete warrant positive pollution considerations. The recycling process also has a favorable impact on the environment. Hence, these materials can be used at a low replacement ratio for construction purposes. For a high replacement ratio, this concrete, which is of low Use for building construction, can be used for construction purposes (non-load bearing). Thus, the low replacement ratio and high replacement ratio of these materials in concrete have been utilized. In both ways, they have worked for the good of the environment.

This scientific point brings new insight, as no research studies the substitution of plastic for fine aggregate. On the other hand, rubber wastes have been incorporated as filler material in concrete.

2 Research objective

The objectives of the present Study are to reveal the fundamental properties of WEC-PS and WEC-RF and determine their suitability for substituting and adding to mixtures.

1) To investigate the properties of WEC-PS and WEC-RF associated with basic engineering, and to examine the possibility of substituting by fine aggregates or as a filler in mixtures.
2) To study how using water-to-cement ratios in lightweight concrete is influenced by replacing fine aggregates with WEC-PS and WEC-RF, and also determine the mixing ratio of WEC-PS and WEC-RF in an admixture.
3) To tackle problems posed by Waste Electrical Cable plastic and Waste Electrical Cable Rubber Filler, ensuring that there is a balance among industrial waste/building materials produced per annum, and
4) Reducing environmental impacts and developing green recycled materials are needed for sustainability.

3 Experimental Work

The concrete can be manufactured within Egypt from local industrial waste, thus reducing business waste effectively and decreasing the carbon footprint of imported construction materials. The practical program for obtaining eco-friendly concrete mixtures is shown in **Fig. 1** below.

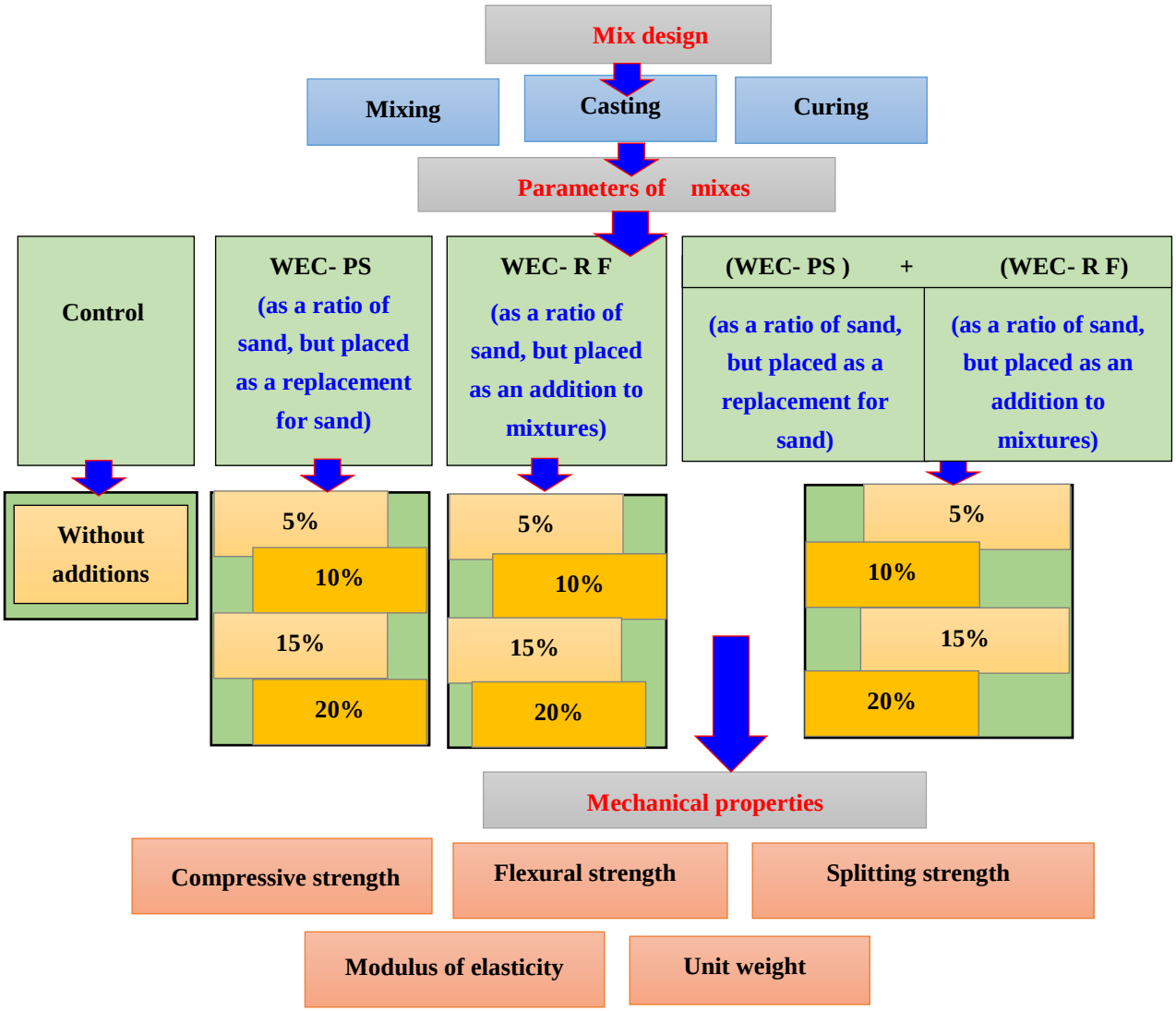

Fig. 1 The practical program of concrete mixtures

3.1 Materials

The cement used was CEM I 42.5 N, which was manufactured following BS EN 197-1 (EN 2000). The Portland cement used in this investigation was Egyptian-brand cement. A local ready-mix concrete company provided the method of Use. The stability of Portland cement is considered to prevent buying expired or moist cement that would affect the quality of concrete. Fine aggregates consisted of natural gravel sieved through sieve no. 4, with a sieve aperture size measuring 4.76 mm. The fineness modulus for fine aggregates varied between 3.2 and 3.1 and should not exceed an allowable variation threshold from standard fineness modulus within ±0.2 as specified in BS EN 196-1 (BSI 2005) specification values. A screening examination found fine sand granularity within the specified range, while water conformed to British standard BS EN1008 (EN 2002). WEC-PS and WEC-RS were added at different percentages of natural sand to improve the properties of lightweight concrete, i.e., 5%, 10%, 15%, and 20%. **Fig. 2** shows grain size distribution (GSD) for WEC-PS, and natural sand.

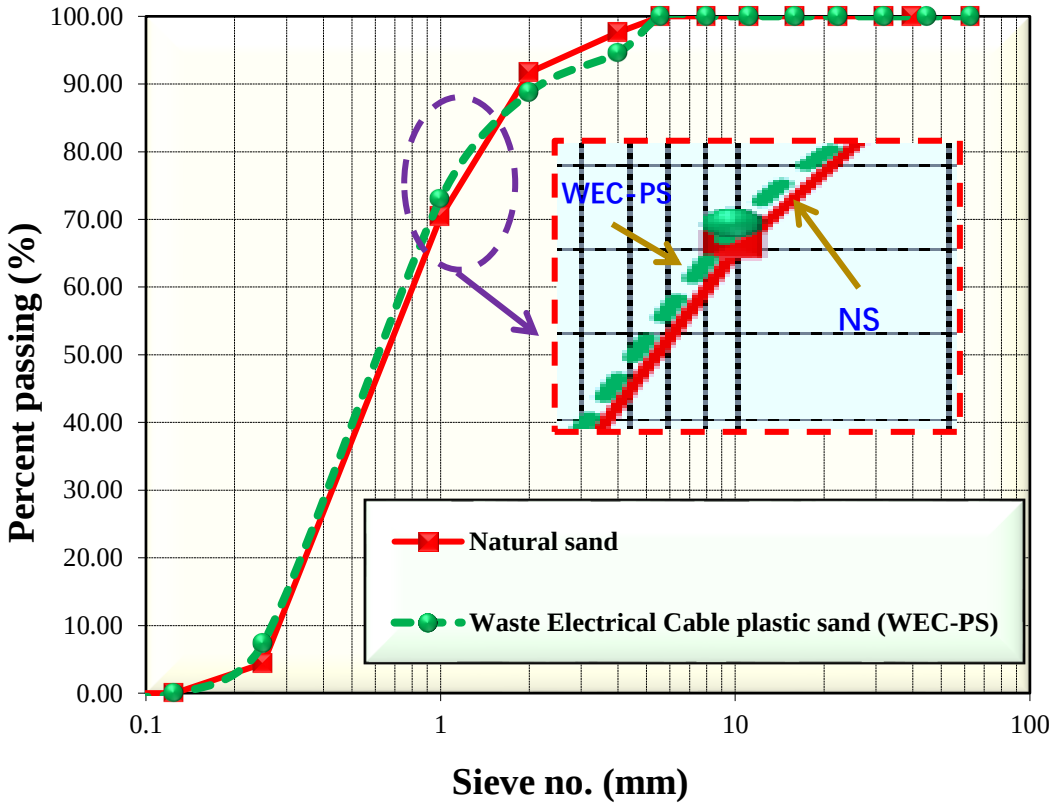

Fig. 2 Grain size distribution for natural sand (NS) and Waste Electrical Cable -plastic sand (WEC-PS)

3.2 Waste Electrical Cable- plastic sand (WEC- PS)

The world generates around 62 million tons of electronic waste, and electrical waste represents about 20% [1, 52, 56]. Waste Electrical Cable production involves several processes as follows:

- Electronic waste collection, specifying the waste from electrical wires and connections.
- It selected waste electrical cables through which the ceiling is wired for the electricity supply.
- The electrical cables are dried in the sun's heat until they become scorched enough to be crushed and ground easily.
- After that, this waste is machine ground, leading to granules of a size like sand grains.
- After that, they are sieved with sieve no. 4 to produce grains as fine as sand (See **Fig. 3**).
- Consequently, grains appear like sand grains; their final name is waste electrical cable -plastic sand (WEC-PS).

3.3 Waste Electrical Cable -Rubber Filler (WEC-RF)

Over 18 million waste electrical cable rubber products are produced annually around the World [1, 65, 78]. There are four steps to manufacturing WEC-RF.

- The first step is to collect waste electrical cable rubber from various sources.
- In the second step, rubber parts are separated from the inner copper wires.
- A grinding machine with a sharp edge reduces it into the tiniest pieces to be used as a concrete filler material (See **Fig. 4**). This makes it suitable for filling because it cannot be smaller than sand grains.
- The final product obtained is waste electrical rubber filler (WEC-RF), the result of all previous operations.

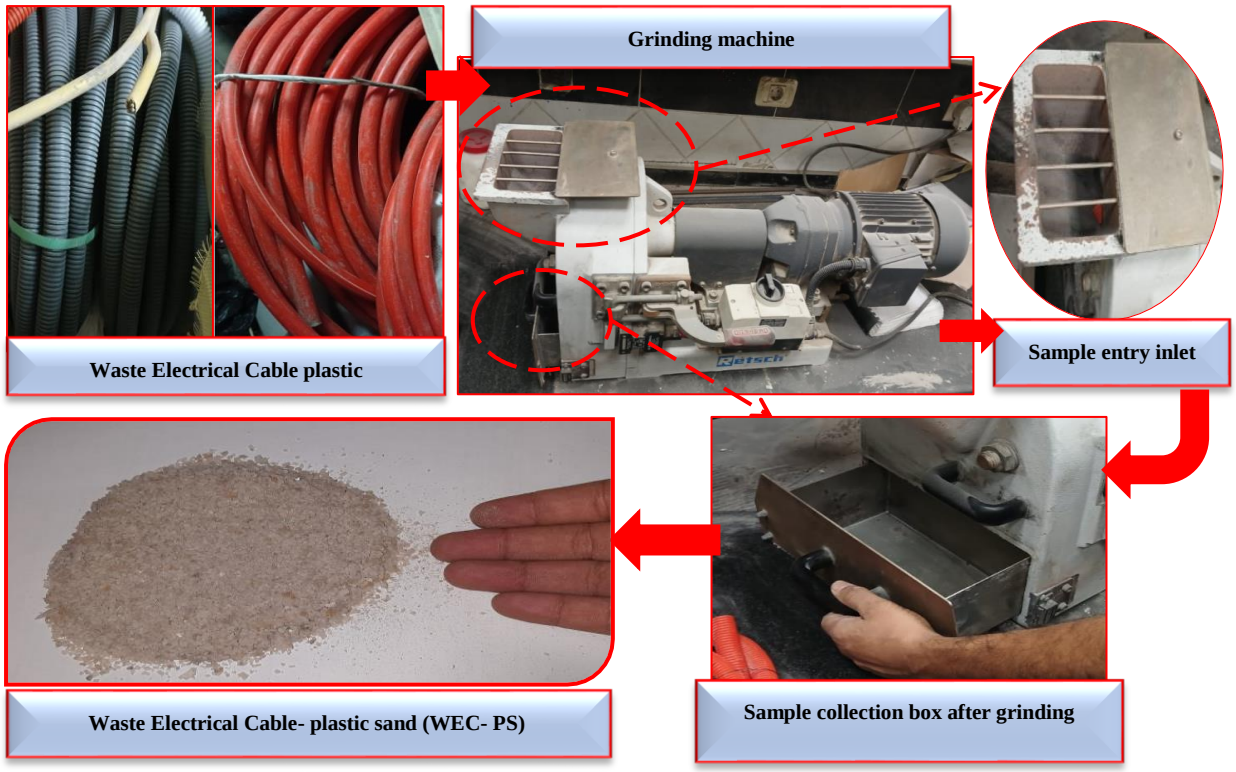

Fig. 3: Method of obtaining Waste Electrical Cable- plastic sand (WEC- PS)

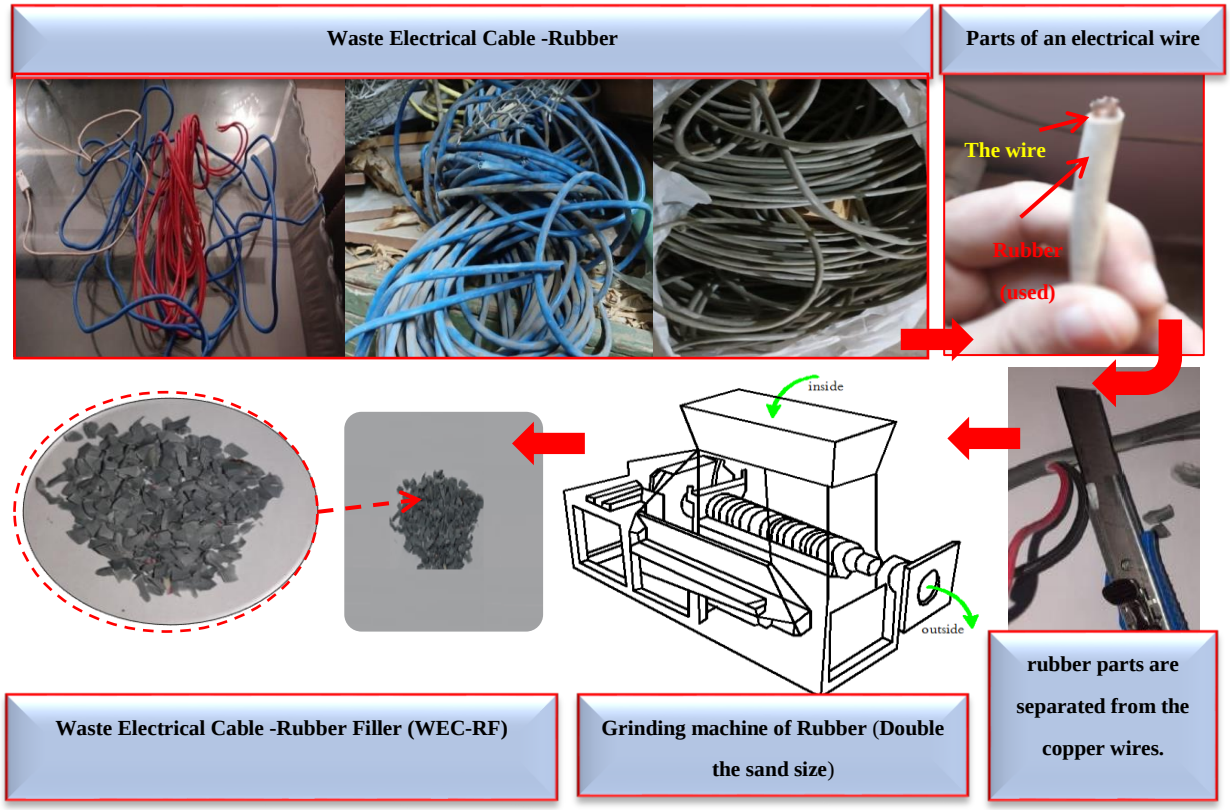

Fig. 4: Method of obtaining Waste Electrical Cable- Rubber Filler (WEC- RF)

3.4 Methods

This research tries to minimize the amount and environmental effects of waste from industries such as waste electrical cables (rubber and plastic). This research also has other benefits, like reducing the usage of natural sandstone and gravel aggregates and preventing the destruction and depletion of natural resources. Fine aggregates were replaced with Waste Electrical Cable plastic sand (WEC- PS), which underwent sieving through a sieve no. 4 (sieve aperture = 4.76 mm); on the other hand, Waste Electrical Cable -Rubber Filler (WEC-RF) served as fillers with a small size of particles and had difficulty in getting fineness such as sand hence they only became a filler to concrete. Previous studies have been carried out on various ratios and an optimum replacement ratio in the replacement of aggregates, so that concrete efficiency is not compromised. On this basis, the ratio that was used for replacement was attained. Different ratios of (WEC- PS) and (WEC- RS) were employed in analyzing engineering properties of lightweight concrete such as first group 5%, 10%, 15%, and 20% for (WEC- PS) as a ratio of sand, but placed as a replacement of sand, second group 5%, 10%, 15%, and 20% for (WEC- RF) as a ratio of sand, but placed as an addition to mixtures, and third group:5%, 10%, 15%, and 20% for (WEC- PS+WEC- RF). The coarse aggregate/ fine aggregate ratio was 1:1.5, and the water/binder ratios were a dose of 0.5% in all mixtures. To achieve consistent and manageable concrete without adding more water, a super-plasticizer Sikament R2004 was utilized at a ratio of 2% of cement. It meets the requirements specified in ASTM C-494 Type G.

The properties of concrete were studied by exposing them to alterations in the engineering parameters of mixtures upon substitution or addition with WEC-PS and WEC-RS, including hardened concrete. The raw materials for lightweight concrete consisted of cement, aggregates, and other additives. Their construction involved blending the right proportions of elements into a mixture before incorporating water at an appropriate level, where everything would be thoroughly mixed.

3.5 Preparation of concrete specimens

Table 1 lists the proportions used in thirteen concrete mixes. The first one is control, which was not made with waste from the industry. The rest are divided into twelve categories: WEC-PS, WEC-RF, and WEC-PS+ WEC-RF categories. All three groups had replacement ratios of 5%, 10%, 15%, and 20% of the sand. The cement-to-water ratio remained the same throughout all the mixes. After several trials with different mixing strategies, an optimal preparation method was arrived at. There should be uniformity in mixtures to make concrete through adherence to a specific mixing technique. Hence, concrete mixtures were mechanically mixed as follows:

1-For 1 min, a pan mixer mixed the fine materials (cement, natural sand, WEC-PS)

2-Another 4 minutes of stirring in the pan mixer as water with plasticizers was slowly poured.

3-Add coarse aggregate or WEC- RF and continue stirring for five minutes until a uniform consistency is achieved.

Table 1: Concrete mixtures components (kg/m^3)

No.		Mixture	Cement	Aggregates				SP (2% of cement)	Water (*W*/*C*=0.5%)
				Fine Agg.	Coarse Agg.	WEC- PS*	WEC- RF**		
1		C0.0%	308	790.27	1185.41	0	0	6.16	154
2	G1	WEC- PS -5%	308	750.76	1185.41	39.51	0	6.16	154
3		WEC- PS -10%	308	711.24	1185.41	79.03	0	6.16	154
4		WEC- PS -15%	308	671.73	1185.41	118.54	0	6.16	154
5		WEC- PS -20%	308	632.22	1185.41	158.05	0	6.16	154
6	G 2	WEC- RF -5%	308	790.27	1185.41	0	39.51	6.16	154
7		WEC- RF -10%	308	790.27	1185.41	0	79.03	6.16	154
8		WEC- RF -15%	308	790.27	1185.41	0	118.54	6.16	154
9		WEC- RF -20%	308	790.27	1185.41	0	158.05	6.16	154
10	G3	(WEC- PS + WEC- RF) -5%	308	770.51	1185.41	19.76	19.76	6.16	154
11		(WEC- PS + WEC- RF) -10%	308	750.76	1185.41	39.51	39.51	6.16	154
12		(WEC- PS + WEC- RF) -15%	308	731.00	1185.41	59.27	59.27	6.16	154
13		(WEC- PS + WEC- RF) -20%	308	711.24	1185.41	79.03	79.03	6.16	154

(* Replaced with sand, ** addition of mix. as rubber filler (RF).

3.6 Testing procedure

The hardened properties of concrete mixtures have been evaluated. The mechanical properties of the concrete mix, such as Compressive strength, Flexural strength, splitting strength, unit weight, and modulus of elasticity, were tested. Cubic samples 150 × 150 × 150 mm^3 in size were subjected to a compression test at 28 days, according to BS EN 1881-116. Prism samples measuring 500 mm × 100 mm × 100 mm were used for flexural and splitting testing after 28 days according to ASTM A, C78/C78M-18, and ASTM A, C496/C496M-17, respectively. Cylinder samples measuring 300 mm × 150 mm were used for static modulus of elasticity testing after 28 days according to Standard A C469/C469M-14. C138/C138M-24a was used to determine physical properties such as unit weight.

4. Results and discussion

Concrete was tested to determine the Effect of substituting or adding aggregate with one, two, or both components on its engineering qualities. The concrete test results are shown in **Table 2**.

Table 2: Results of Concrete mixtures at 28 days

No.		Mixtures	Compressive strength (MPa)	Flexural strength (MPa)	Splitting strength (MPa)	Modulus of elasticity (MPa)	Unit weight (T/m^3)
1		C0.0%	25.75	3.21	2.65	18688	2.51
2		WEC- PS -5%	30.41	3.97	3.55	22069	2.58
3		WEC- PS -10%	29.44	3.91	3.38	21365	2.57
4	G 1	WEC- PS -15%	28.31	3.71	3.15	20545	2.55
5		WEC- PS -20%	23.45	2.91	2.38	17018	2.50
6		WEC- RF -5%	25.89	3.31	2.73	18789	2.52
7		WEC- RF -10%	23.25	2.87	2.28	16873	2.48
8	G 2	WEC- RF -15%	22.11	2.69	2.13	16045	2.43
9		WEC- RF -20%	21.15	2.58	2.01	15349	2.41
10		(WEC- PS + WEC- RF) -5%	29.07	3.84	3.28	21096	2.56
11	G 3	(WEC- PS + WEC- RF) -10%	27.97	3.53	3.08	20298	2.54
12		(WEC- PS + WEC- RF) -15%	26.01	3.37	2.82	18876	2.53
13		(WEC- PS + WEC- RF) -20%	22.65	2.77	2.19	16437	2.45

4.1 Influences of WEC- PS and WEC- RF on compressive strength

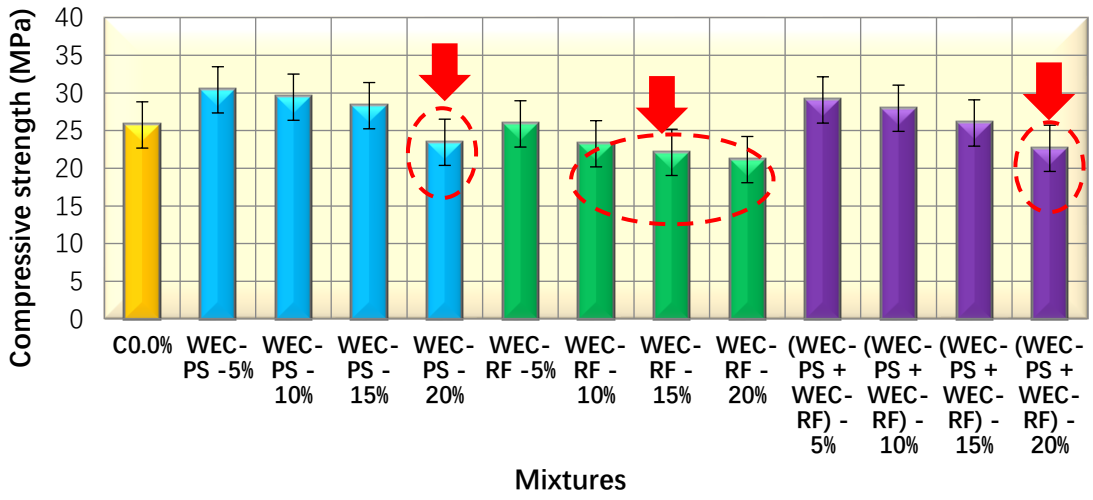

Fig. 5 Compressive strength of sustainable concrete

The sustainable concrete's compressive strength falls in the structural grade category for every replacement or addition percentage using WEC- PS, WEC- RF, and WEC- PS +WEC- RF at all replacement levels. When only WEC- PS -5%, WEC- PS 10%, and WEC- PS 15% replaced small fractions of sand, the increase was 18.10%,14.33%, and 9.94%, respectively[27, 28]. However, natural sand was replaced by WEC-PS at 20%, thus decreasing compressive strength by 8.93% after

28 days, as indicated in **Fig. 5**.

If it is possible to add WEC-RF-5%, the concrete strength can be increased by about 0.54% at a ratio of 5%. **Figs. 5 and 6** show that when the WEC-RF -10% to WEC-RF -20% were added, there was a fall of about 9.71% to 17.86% [29, 30]. It seems obvious that replacing natural sands with WEC-PS up to 15% or adding WEC-RF up to 5% increases the mechanical properties of concrete. However, the situation changes when using in large ratios [22, 31]. At high ratios, Loss increased sharply compared with each other concerning their replacement or addition ratio, depending on what they are made of, and some properties that would differ during their manufacturing processes due to different materials.

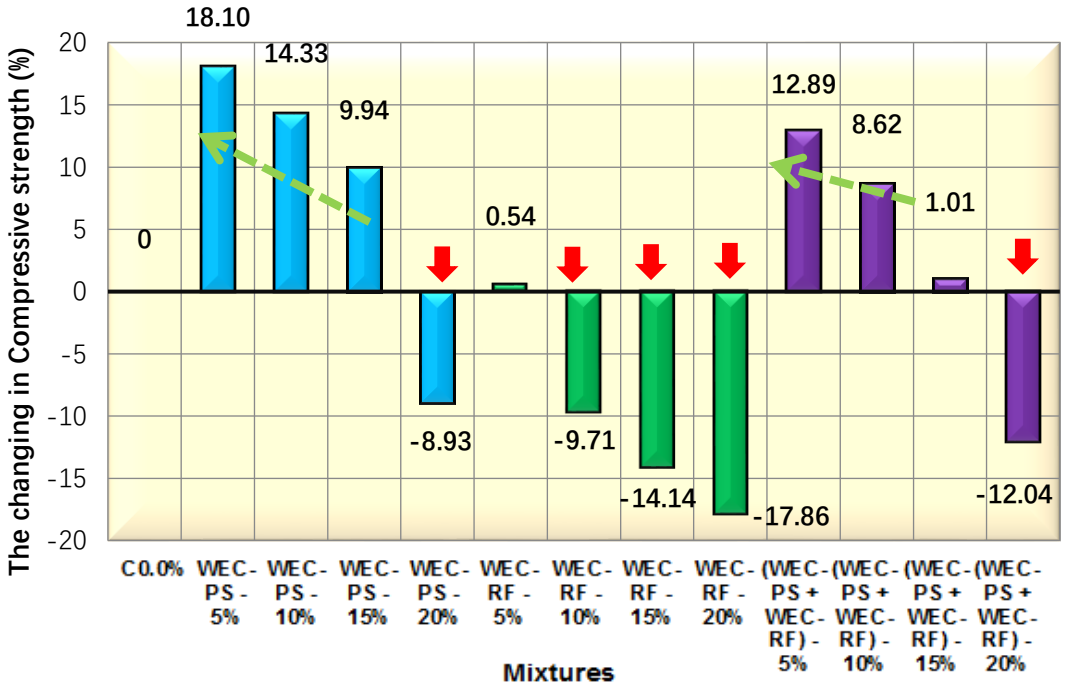

Fig. 6 The changing in Compressive strength (%)

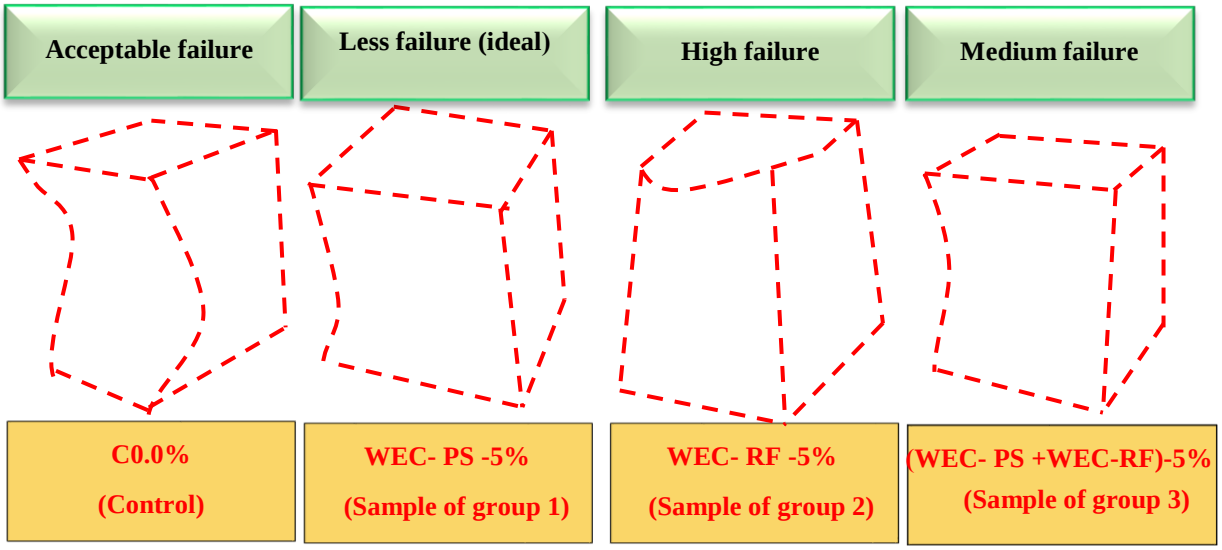

Fig. 7 Sketch of failure Shape for sustainable concrete (After the samples failure in the laboratory test)

Finally, there is an increase in strength rate from using (WEC- PS + WEC- RF) -5% by 12.89% onwards, followed by replacement rates of (WEC- PS + WEC- RF) -10% by 8.62%, and finally by replacement rates of (WEC- PS + WEC- RF) -15 % by 1.01%. It decreased by 12.04% after

replacement and addition to the mixture (WEC-PS + WEC-RF) -20%. [32, 33].

On the contrary, increasing (WEC-PS + WEC-RF) decreases compressive strength; however, (WEC-PS + WEC-RF) improves the shape and mode of failure in the tested cubes compared to the control sample; **Figs. 7 and 8** show Failure shape of the selected samples, thereby increasing final strength at a low replacement or addition ratio of (WEC-PS + WEC-RF)[34, 35], as shown in **Figs. 6,7 and 8**.

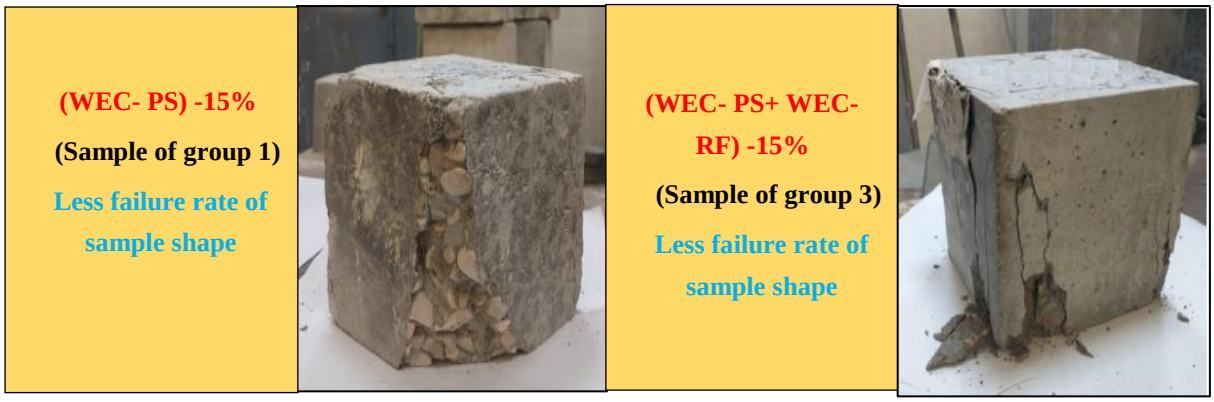

Fig. 8 Failure shape of the selected samples

4.2 Influences of WEC- PS and WEC- RF on flexural strength

Fig. 9 demonstrates that the flexural strength of sustainable concrete at 28 days decreases by 9.35% when WEC-PS-20 % replaces natural sand. The percentage decreases to 19.63% if the highest is added with WEC- RF-20%, corresponding to a volume replacement of 20% [36, 37]. When natural sand is replaced with WEC-PS and WEC-RF is added to mixtures, which equates to a ratio of 20%, the strength reduction is about 13.71%. On the other hand, when addition WEC- RF-20%, follow (WEC- PS + WEC- RF-20%) together, follow WEC- PS-20%, This records the order of descending rates in ascending order on compared to the control flexural strength (**Fig. 10**), which show the respective strengths decreasing rates of:19.63%, 13.71% and 9.35%[38, 39], respectively.

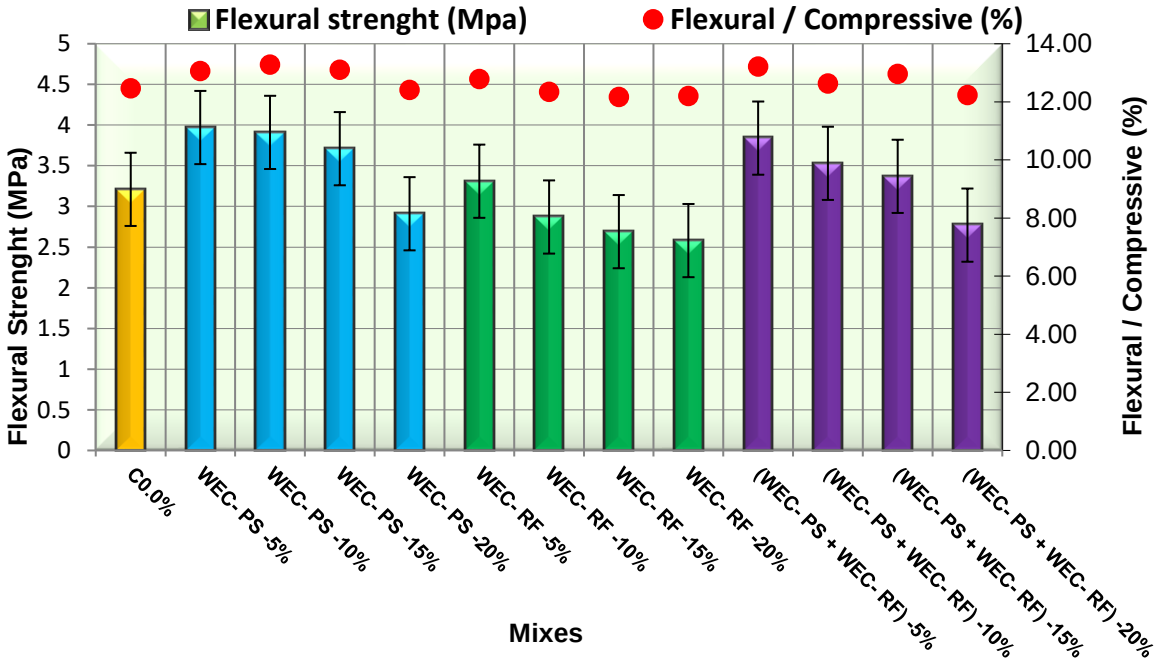

Fig. 9: Flexural strength and flexural/compressive strength (%)

Fig. 9 shows the relationship between the concrete's compressive and flexural strengths. This figure provides a suitable image of the concrete mix and indicates that there are lower voids or pores

and a properly shaped interface zone within the specimen's construction (at low replacement or addition). These surfaces make the structure solid and thus increase its density.[40, 41]. The particles are connected via tiny, porous zones at low replacement and addition rates and paste, raising the strength of concrete, as evidenced by its excellent behavior. Higher replacements or Higher additions for WEC- PS, and WEC- RF in the concrete mix result in more voids and weak concrete structures[42, 43].

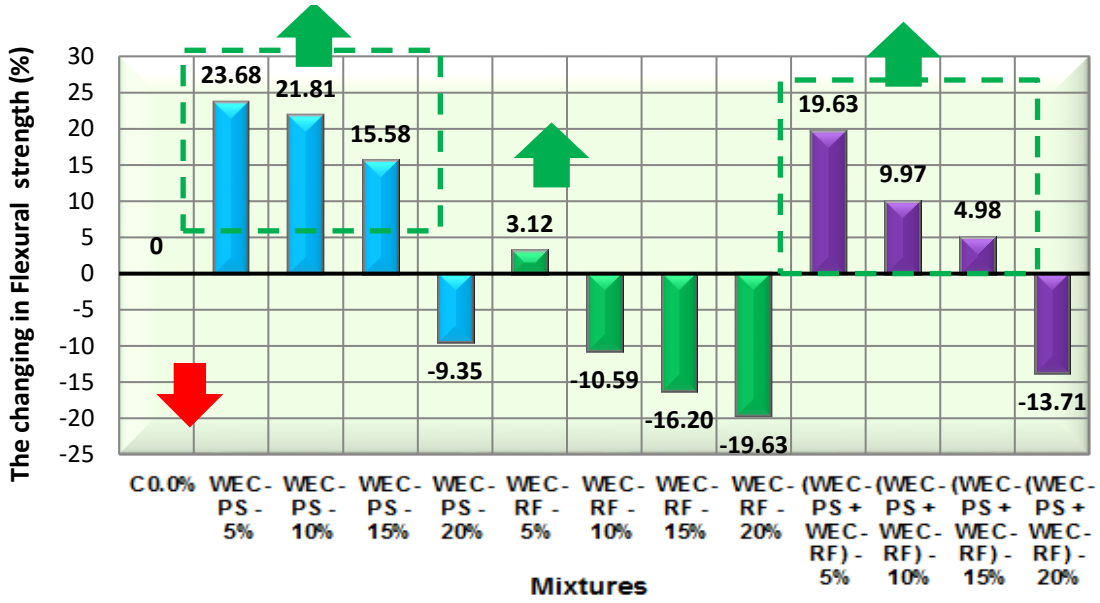

Fig. 10: The changing in flexural strength (%) of sustainable concrete

4.2.1 Relationship between compressive strength and flexural strength

To investigate the Relationship between sustainable concrete's compressive strength and its flexural strength is what this section does. The best-fit line for the Relationship is as follows: This Relationship is shown in **Fig. 11**.

$$Y = 0.1469x - 0.5285 \quad \ldots\ldots (1)$$

Where X is the compressive strength (MPa), Y is the flexural strength (MPa), and the R^2 value, which gives the equation's accuracy, is found to be somewhat appropriate, i.e., 0.9609.

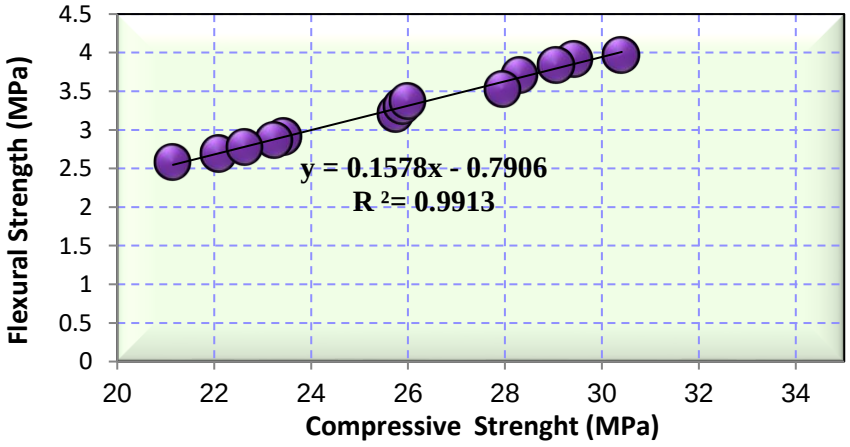

Fig. 11: Correlation between flexural and compressive strength

Fig. 11 illustrates the Relationship between compressive strength and flexural strength of specimens. Due to the different combinations, low variations are recorded; thus, it is assumed that the connection applies to all concrete mixes. The line fitted in **Fig. 11** shows a stronger correlation than

the other graphs and with fewer fluctuations[44, 45]. Therefore, the accuracy of predicting the compressive strength of specimens using their flexural strength is given by R^2. It can be concluded from this that the flexural strengths of concretes increase with increased compressive strengths of concretes[46, 47].

4.3 Influences of WEC- PS and WEC- RF on splitting strength

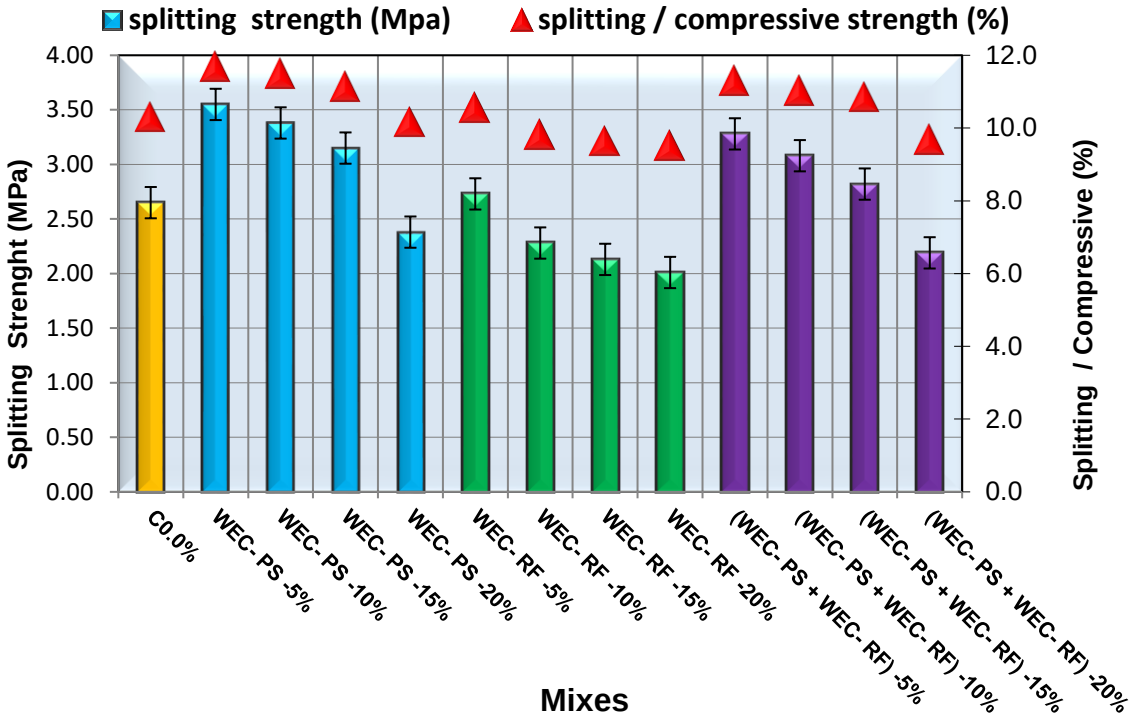

Fig. 12: Splitting strength and splitting /compressive (%)

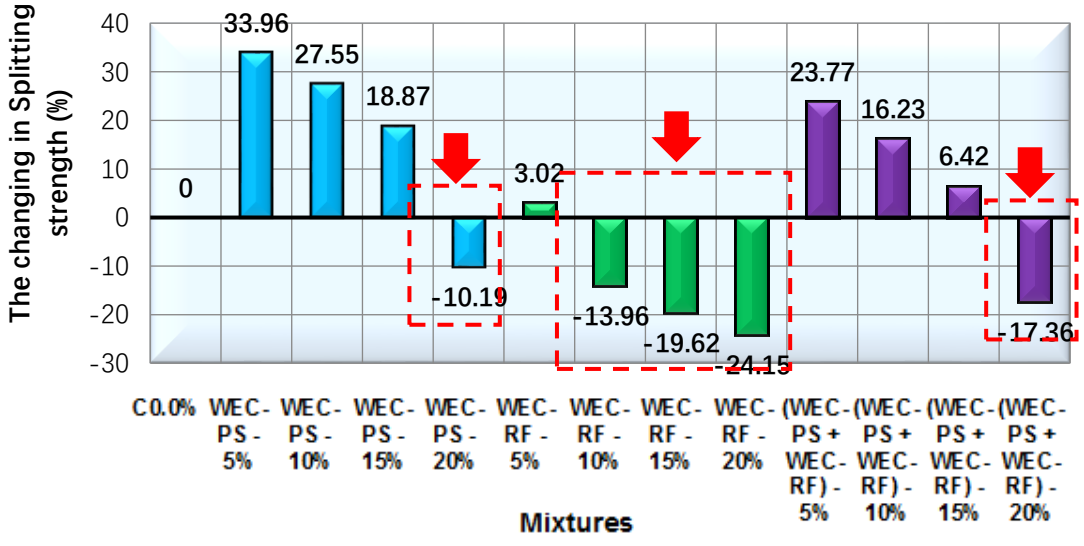

Fig. 13: The changing in splitting strength (%) of sustainable concrete

Fig. 12 shows the increase of splitting strength at 28 days for sustainable concrete when natural sand is substituted by 5%,10%, and 15% of WEC- PS (first group), addition 5% of WEC- RF (second group), and finally, replacement and addition 5%,10%, and 15% of (WEC- PS + WEC- RF) (third group) as observed in **Fig. 12**. Also, with a sand replacement of 20%, this lowers by 10.19% if only the most significant fraction of sand is replaced by WEC- PS [48-50]. On the other hand, for (WEC-

PS + WEC- RF) -20% replaces natural sand at a volume replacement of 10% and addition of WEC-RF at a ratio of 10%, then its strength reduces by 17.36%;

On the other hand, splitting strength addition WEC- RF reduction in splitting strength by about just under 24.15% when addition WEC- RF -20%, it happens as shown in **Fig. 13**. The rate at which splitting strength decreases seems to be similar to that reported in Previous studies for replacement WEC- PS, addition WEC- RF, and replacement or addition (WEC- RF+WEC- PS)[51, 52].

Figs 12 and 14 show the linear correlation between compressive strength and splitting strength of concrete, indicating fewer pores and voids below the surface and confirming the existence of a well-defined interfacial area in the sample (at low substitution rates)[53-55]. Small porous regions at low replacement ratios strongly bond granules with paste, leading to higher strengths for concrete, as seen in its strong performance. As WEC-PS and WEC-RF ratios increase in the concrete mix, more empty spaces result and weakly constructed concrete.[56, 57].

4.3.1 Relationship between Compressive Strength and Splitting Strength

The Relationship between compressive strength and splitting strength is studied in this portion of the experiment. As seen in **Fig. 14**, a best-fit line representing this Relationship can be described mathematically as follows:

$$Y = 0.1676x - 1.5842 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

X is the compressive strength (MPa), Y is the splitting strength (MPa), and the equation's correctness is evaluated using the R^2 value, which is somewhat appropriate at 0.9945.

Fig. 14 shows the associations between the specimens' compressive and splitting strengths. The connection is deduced from every concrete mixture due to the low variations in results with different combinations. Consequently, distinct relationships for each mix are hoped to give accurate results [58-60]. This line looks better suited to the graph than those above; hence, it fluctuates less. Thus, it is represented by R^2, which provides precision regarding the projection of the compressive strength of specimens using their splitting strength. The only conclusion that can be drawn here is that an increased relationship exists between concrete's splitting and compressive strength [61, 62].

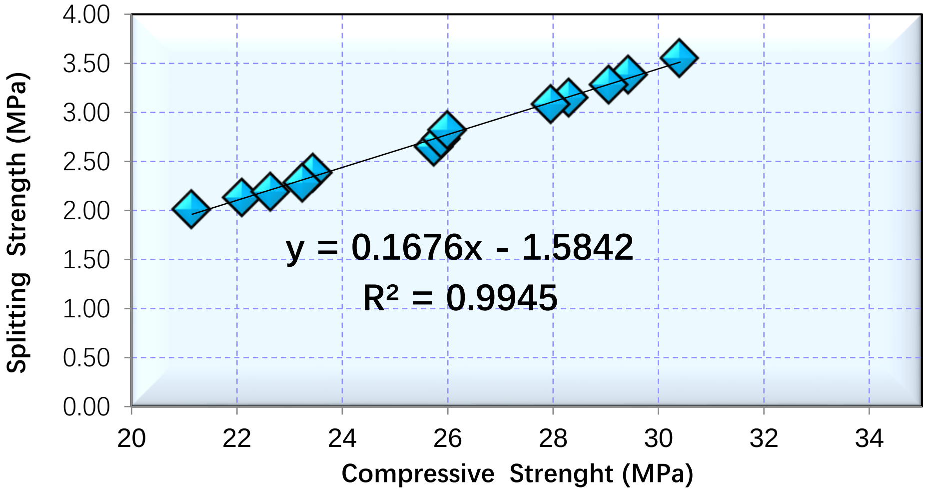

Fig. 14: Correlation between Splitting and compressive strength

4.4 Influences of WEC- PS and WEC- RF on the modulus of elasticity

The modulus of elasticity was determined to assess the deformation behavior of sustainable concrete without and with natural sand or any addition. The control mix C0.0% was taken as a reference elastic modulus for comparison purposes [63-65]. As **Figs. 15&16** shows the modulus of elasticity of sustainable concrete with WEC- RF or WEC- PS also follows a similar increasing trend when WEC- RF-5% or WEC- PS-5% or (WEC- RF + WEC- PS-5%) content is increased at approximately 18.09%, 0.54% and 12.89 %, respectively, until the peak strength is attained at a replacement, addition, or replacement with addition at ratio of 5 % for group I, II, and III mixes

respectively[66, 67].

After reaching its peak, however, this curve decreased gradually as the ratio continued to increase WEC- RF, WEC- PS, or WEC- RF + WEC- PS. In addition, mixes with WEC- RF performed poorly compared to those containing WEC- PS or (WEC- RF + WEC- PS) [68, 69]. This drop is due to decreased compressive strength at low strain values for sustainable concrete (**Figs. 15 and 16**). Low modulus elasticity of Various sustainable concrete Mixtures with (WEC- RF, WEC- PS, or WEC- RF + WEC- PS) Can Be Attributed to inner cracks at matrix interfaces that result in Feeble low strength between WEC- RF, WEC- PS, or WEC- RF + WEC- PS at high replacement or addition. Concrete Matrix Group I mixes containing WEC-PS have a higher elastic modulus than Group II mixes containing WEC-RF because they are more compressible. The lesser impact of WEC-RF on modulus could be attributed to the weak interface transition zones between it and the cement paste [70-72].

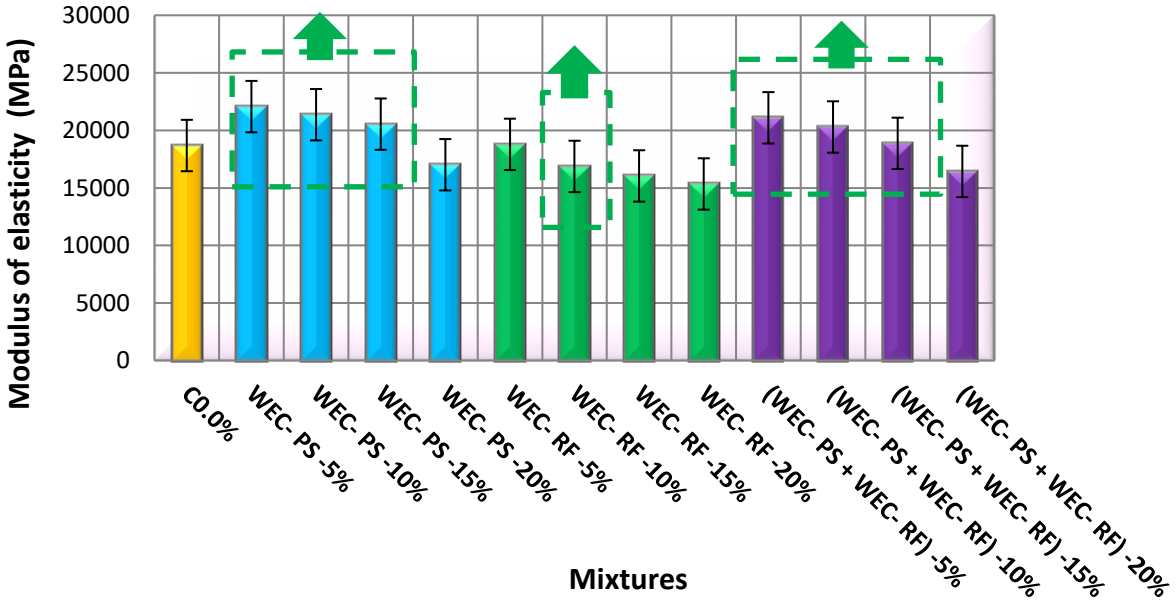

Fig. 15: Modulus of elasticity for all mixtures

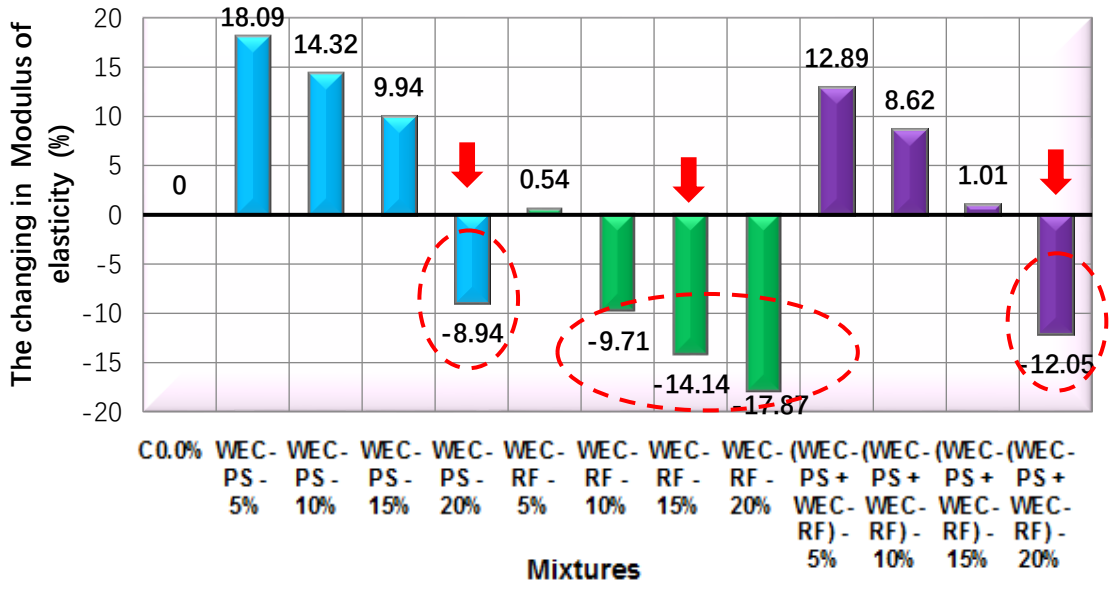

Fig. 16: The Changing in modulus of elasticity (%) of sustainable concrete

4.5 Influences of WEC- PS and WEC- RF on the unit weight

Fig. 17 shows WEC-PS, WEC-RF, and WEC-RF + WEC-PS unit weights. Hardened WEC- PS concrete weighs between 2.58 t/m^3 and 2.50 t/m^3, as opposed to WEC- RF, which weighs between 2.52 t/m^3 and 2.41 t/m^3, while WEC- RF + WEC- PS weighs between 2.56 t/m^3 and 2.45 t/m^3 in terms of its unit weight [73, 74]. **Fig. 18** shows that the unit weight of concrete is affected by the specific gravity of the ratio replacement of (WEC-PS) or the ratio addition of (WEC-RF).

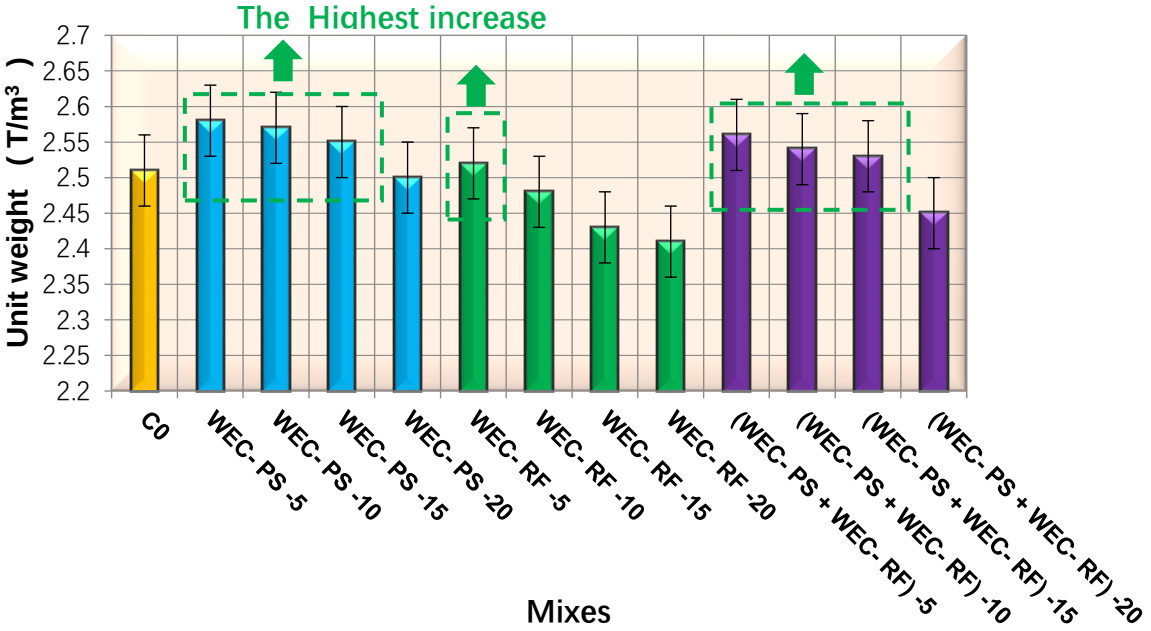

Fig. 17: Unit weight for all mixtures

By increasing the WEC-PS replacement ratio from 5% to 20%, the unit weight drops gradually to a certain extent, reaching a minimum limit. For example, when we compare experimental results with the control mix, four points are available for verifying such statements: 5%, 10%, 15%, and 20% [75-77]. The replacement of natural sand has reduced the unit weight. For instance, the unit weight for specimen WEC-PS-20% is lower than that of the control mix by about 0.40%. On the other hand, replacing natural sand has reduced the unit weight. For instance, the unit weight for specimen WEC-RF-20% is lower than that of the control mix by about 3.98%. However, the increase in WEC-RF showed reductions in unit weight upper than WEC-PS [78-80].

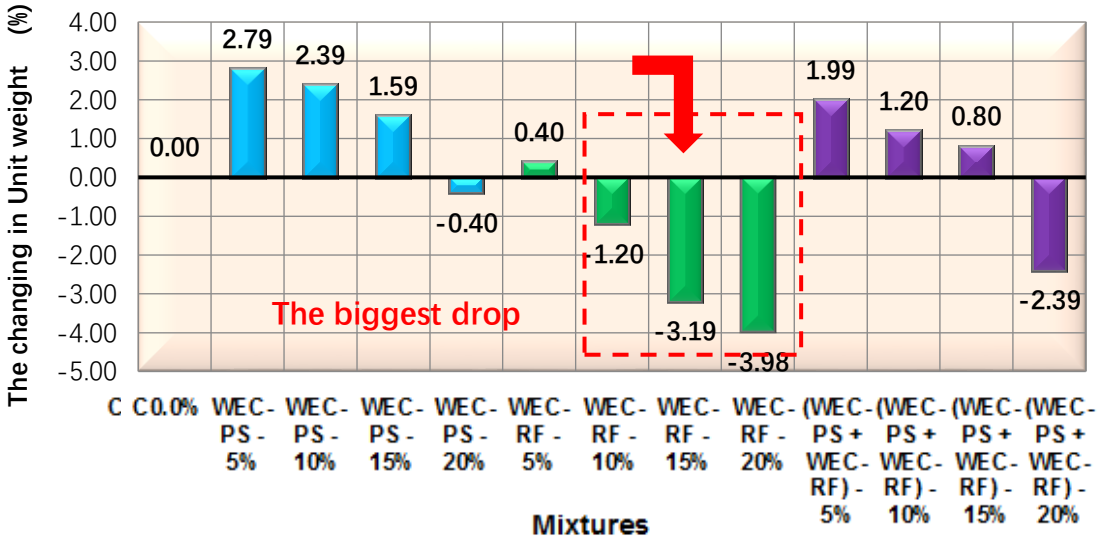

Fig. 18: The Changing in Unit weight (%) of sustainable concrete

5. Conclusion

This Study examined the Influence of WEC-PS, WEC-RF, and the combination of WEC-RF + WEC-PS on the mechanical properties of green concrete. The results are presented in summary as follows:

When only WEC- PS -5%, WEC- PS 10%, and WEC- PS 15% replaced small fractions of sand, the increase was 18.10%, 14.33%, and 9.94%, respectively.

It seems obvious that replacing natural sands with WEC-PS up to 15% or adding WEC-RF up to 5% increases the mechanical properties of concrete. However, the situation changes when using in large ratios.

When natural sand is replaced with WEC-PS and WEC-RF is added to mixtures, which equates to a 20% ratio, the flexural strength reduction is about 13.71%.

The Relationship between the compressive and flexural strengths of the concrete, which gives a suitable image of the concrete mix and also indicates that there are lower voids or pores as well as a properly shaped interface zone within the specimen's construction (at low replacement or addition). On the other hand, higher replacements or higher addition for WEC- PS, and WEC- RF in the concrete mix result in more voids and weak concrete structures.

It shows the increase of splitting strength at 28 days for sustainable concrete when natural sand is substituted by 5%, 10%, and 15% of WEC- PS (first group), addition 5% of WEC- RF (second group), and finally, replacement and addition 5%, 10%, and 15% of (WEC- PS + WEC- RF) (third group).

Concrete Matrix Group I mixes containing WEC-PS have a higher elastic modulus than Group II mixes containing WEC-RF because they are more compressible. The lesser impact of WEC- RF on modulus could be attributed to the weak interface transition zones between it and the cement paste

Hardened WEC- PS concrete weighs between 2.58 t/m^3 and 2.50 t/m^3, as opposed to WEC- RF, which weighs between 2.52 t/m^3 and 2.41 t/m^3, while WEC- RF + WEC- PS weighs between 2.56 t/m^3 and 2.45 t/m^3 in terms of its unit weight.

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Credit authorship contribution statement

Raghda Osama Abd-Al Ftah: Supervision, Investigation, Formal analysis, Writing – original draft. **Radwa Defalla Abdel Hafez**: Supervision, Investigation, Formal analysis, Writing – original draft.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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