

Sustainable Mortar Made with Local Clay Bricks and Glass Waste Exposed to Elevated Temperatures

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Abstract

The present study involved assessing the replacement of fine aggregate in the mortar with sustainable local materials like clay bricks and glass included 168 specimens (cubes and prisms). Seven mixtures were cast for this work, one control mix (R1) with 100% natural sand whereas mixes from R2 to R5 have 10% and 20% replacing natural sand with waste clay bricks and waste glass separately and respectively. Mix R6 was included 20% replacing sand with combination waste materials (10% waste clay bricks with 10% waste glass). Mix R7 has involved the same percent of replacing the previous mix R6 but with adding Polypropylene fibers 1% by volume. The samples have put in an electrical oven for one hour at 200, 400, and 600 °C then cooled to room temperature to be tested and compared with samples at normal temperature 24 °C. Different mechanical tests were adopted involved flow tests, density, weight loss, compressive strength, flexural strength, and water absorption. The results at different temperatures were discussed where many findings were specified. The flexural strength at 400 °C was showed improving by 56% for 20% waste clay brick and 69% with 10% waste glass, as well all combination mixes illustrated higher strength than the control.

Keywords: High Temperatures; Sustainable Materials; Recycle Aggregate; Compressive Strength.

1. Introduction

One of the challenges faces generally human beings and especially researchers, is pollution, due to the accumulation of demolition constructions or by-product materials from manufacturing. The use of such recyclable materials in construction is considered eco-friendly and appropriate to reduce serious problems such as nonbiodegradability, accumulation of wastes, and protect natural resources from consumption. On the other hand that would open the field forwards the researchers to explore the desirable produced characteristics and the limitations [1-5].

Waste produced from the construction and building manufacture has increased internationally, includes clay bricks and concrete demolition. The United States was produced about 170 million tons of related materials in (2003), as well, Canada produced in (2004) 15.5 million tons, and in (2008) 17.3 million tons [6]. Numerous researches investigated the ability to use the waste of clay bricks in mortars, and have been obtained promising results [7-8]. Bektas et al. (2009) [9] studied experimentally the impacts of recycling the clay bricks replaced parts of the natural sand on the properties of mortar. The results indicated that the mortar flowability was reduced as the percent of replacement increased, but there was a limited effect on the compressive strength. The characteristics and

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microstructure of mortars made with a waste of red clay bricks were studied (2013) [10]. The research shows the ability to increase the compressive strength of the studied samples from 30 MPa to 50 MPa through optimization of the type and concentricity of alkali activator, in addition to reusing of this notable waste material at the same time. The study of Dang (2019) [11] was based on different parameters such as different replacement ratios and particle size of the recycled brick (RCBA) and additional water content to understand its effect on the flowability, flexural strength, and compressive strength of mortars. The study extended to analyzing the microscopic morphology of Recycled Clay Bricks Aggregate (RCBA) and showed a decline of the physical properties of RCBA due to the porous structure and mechanically crushing treatment. There is interest in exploring the performance of recycled aggregate under high temperatures over the years. Khalaf et al. (2004) [12] investigated the properties of the concrete cast with crushed clay bricks subjected to high temperatures. The experimental program involved crushed clay bricks as coarse aggregate (two different strength) and natural granite aggregate. The results pointed out that the performance of clay bricks concrete rather good or maybe better than granite concrete. Concrete made with waste clay bricks industry exhibited satisfactory mechanical properties at normal temperature and better fire resistance than the concrete made with river aggregates [13].

Glass waste is categorized as a nonbiodegradable residual solid, an alternative solution to avoid its accumulation in landfills is to use it in construction as a minimal to mitigate this serious environmental problem [2]. In the United States in (2015), glass generation was 11.5 million tons, whereas approximately 7 million tons of waste of glass was received in landfills only in that year [14]. Numerous studies assessed the reuse of waste glass powder (WGP) substituted partially with cement. Tan and Du (2013) investigated the suitability of mortar that contained waste glass (as a partial and full replacement of fine aggregate) for construction purposes. The results of flowability were reduced, but there is an increase in mechanical properties [15]. Özkan et al. (2008) [16] investigated many features of mortars containing waste glass, one of them was the high-temperature resistance. Positive results were observed for all samples subjected to different high temperatures, particularly at 300 °C. Generally, the concretes made with 10% replacing fine waste glass aggregate, coarse waste glass aggregates, and fine and coarse glass aggregate had better characteristics for fresh and hardened states at normal (ambient) and high temperatures than those with normal aggregate [17]. Rashad (2014) presented the fresh and dry density of concrete decreased with increasing content of waste glass aggregate. The water absorption reduced as regarding to mixture without glass due to negligible water absorption of the recycled glass. The residual compressive strength increased with incorporated 10% of glass as fine aggregate in concrete that exposure to 700 °C [14]. Guo et al. (2015) studied the mechanical properties of SCAM (self-compacting architectural mortar) containing RG (recycled glass) at room temperature and when exposed to high temperatures. Increasing the RG content hurts the compressive strength at room temperature, while beneficial effects on the mechanical properties were observed for (SCAM) at 800 °C [18].

Assessment of the behavior of mortar which contained recycled materials such as clay bricks or glass at high temperature not clear yet. Especially, the mortar containing local waste materials (Iraqi clay brick and glass) so a need to do more researches in this field. This work focuses on utilizing sustainable local materials (clay bricks and glass) as a partial replacement for sand reaches 20% of replacing. One of the most important difficulties that we faced in this research is grinding the recycled materials (clay bricks and waste glass) and making them as fine as natural sand, especially glass, which grinds easily because it is a brittle material. The specimens were exposed to different temperatures 24, 200, 400, and 600 °C. The flow, compressive strength, flexural strength, density, weight loss, and water absorption was tested for evaluating the effect of elevated temperature on the mortar having recycled materials.

2. Materials and Methods

Different materials were employed in the present study for mix designs to produce mortar. Those materials including Portland cement, normal sand, recycle materials (sustainable materials) clay bricks, and glass as partial replacing for natural sand, superplasticizer, and Polypropylene fibers. Type II Portland cement (CEM II/A-L 42.5R) supplied from a local source called Karasta was depended on in this work and complied with Iraqi Specification No. 5 [19] as presented in Table 1. Natural fine aggregate in the Saturated Surface Dry (SSD) condition with a maximum size of 1.18 mm was used in the present paper. Master Glenium 54 (superplasticizer) from BASF Company for modified workability for fresh state mortar was used and conformed to ASTM C494 Type F [20].

Waste clay brick (parts) resulting construction building was used. The clay brick from the local factory (ASO) complies with the Iraqi Specification No. 25. Waste glass collected from broken bottles, the recycled glass goes through several stages before use. The waste glass was washing, cleaning, and then drying. The recycled materials (clay bricks and glass) were manually crushed and sieving range of 1.18 to 0.15 mm for use as sand replacing. The waste materials were used in Saturated Surface Dry (SSD) condition, for that the recycled clay bricks and glass soaked in water for 12 hours after that dried the surface. The sieving analysis of natural fine aggregate (sand) and the recycled materials was presented in Table 2, and Figure 1 according to Iraqi standard No. 45 [21]. The cement mortar was reinforced by using Polypropylene fibers from Sika Company where the properties are presented in Table 3.

Table 1. Cement lime chemical composition

Cement chemical composition	
Oxides	Content, %
CaO	63.2
SiO ₂	20.2
Al ₂ O ₃	4.6
Fe ₂ O ₃	3.8
MgO	3.1
SO ₃	1.8
Free lime	0.8
Loss on Ignition	3.0
Lime Saturation Factor	0.85
Insoluble residue	1.1
Initial setting time (min)	55
Final setting time (hr)	3.6
Compressive strength in 3 days	28.7

Table 2. Sieving analysis of natural and recycled fine aggregate

Sieve opening (mm)	Iraqi specification No.45	Percentage passing, %		
	Grading Zone III	Natural sand	clay brick	Waste glass
2.36	85-100	100	100	100
1.18	75-100	100	100	100
0.60	60-79	72.5	73.5	76
0.30	12-40	34.6	33.3	37.5
0.15	0-10	3.6	4.8	5.3

Table 3. Properties of polypropylene fiber

Properties of polypropylene fibers			
Length (mm)	12	Melting point (°C)	160
Demeter (mm)	0.032	Ignition point (°C)	365
Density (kg/m ³)	910	Specific surface area (m ² /kg)	250
shape	Straight	Absorption	Nil
Tensile properties MPa	700 - 6600	Melting point (°C)	160

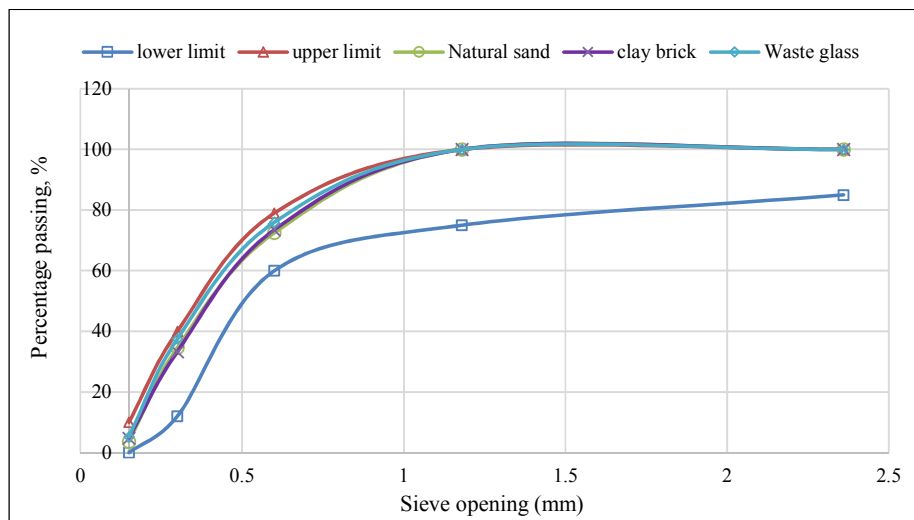


Figure 1. Sieving analysis for natural and recycled fine aggregate

The cement/sand was (1:2.75), and water/cement (0.35) whilst, the dosage of Glenium 54 (superplasticizer) was 2.5% by cement weight, all these percentages were fixed for all mixtures. Seven mixtures were cast in this work: the first one controlled mix (R1) with natural sand only 100% and whereas mixes from (R2 to R5) has 10% and 20% replacing natural sand by waste materials (recycles materials) clay bricks, and glass separately and respectively. Mix R6 was involved 20% replacing sand with combination waste materials (10% waste clay bricks with 10% waste glass). Mix R7 has included the same percent of replacing the previous mix R6 but with adding fibers (Polypropylene) 1% by volume. Table 4 illustrated all details of the mixes.

Table 4. Details proportions mix for mortar (g)

Mix designation	Cement	Sand			Water/ Binder	SP	Polypropylene fibers
		Natural	WB	WG			
R1	500	1375	0	0	175	12.5	0
R2	500	1237.5	137.5	0	175	12.5	0
R3	500	1100	275	0	175	12.5	0
R4	500	1237.5	0	137.5	175	12.5	0
R5	500	1100	0	275	175	12.5	0
R6	500	1100	137.5	137.5	175	12.5	0
R7	500	1100	137.5	137.5	175	12.5	7.69

WB: waste clay bricks, WG: waste glass, SP: Superplasticizer.

* This table was calculated for three prisms of mortar with dimensions 40×40×160 mm.

Standard mechanical mixer complies with ASTM C305 [22] used for mixing mortar. The procedure for mixing was including the following steps: all materials were put in a bowl for dry mixing with a low speed of 140 rpm for two minutes. The water and Master Glenium 54 (superplasticizer) (mixed previously together) added to dry materials and mixed for one minute at low speed. Then, the mixer stopped for a rest period (one minute). Afterward, all ingredients were mixed at a high speed of 285 rpm for four minutes. While the mixture having fibers, the mixing going on for four and a half minutes more (half a minute for fiber gradually adding and four minutes for mixing at 285 rpm). After mixing the fresh mixtures was used for flow testing thereafter the mortar cast in cubes and prisms (standard molds) and vibrated. Within 24 hours remove the molds and stored specimens in water tanks for 28 days at room temperature. The samples were put in the electrical oven for one hour at 200, 400, and 600 °C then cooling to room temperature and adopted for different testing were the outcomes used for comparing with samples at normal temperature 24 °C. Figure 2 showed the methodology of research.

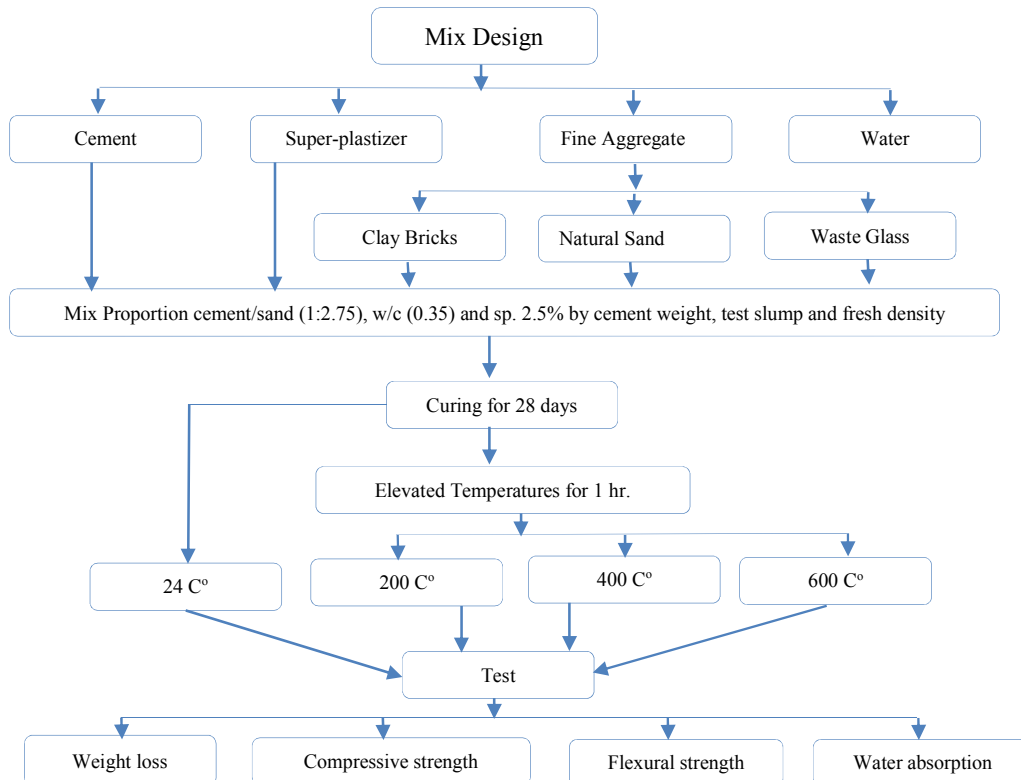


Figure 2. Flowchart of research methodology

Many trial mixes were neglected, especially at a high percent of replacing recycled material (30% for clay bricks and above) with natural aggregate due to the difficulty of mixing where the slump was zero and the specimens have a high percentage of voids that effect negatively on the mechanical properties. Figure 3 illustrated the spacemans in air and in oven, slump test and flexural strength test.



Figure 3. The experimental samples with slump and flexural strength test

3. Results and Discussions

3.1. Flow Test

The flow test of mortar was conducted according to ASTM C1437- [23]. Figure 4, and Table 5 presents the effect of waste materials on the flow test of mortar. The control mix showed the highest flow as regarding other mixes. The flow rate lowered by 7% for 10% replacing waste clay bricks and 27% for 20% as comparing with the control mix. It is apparent that the flow of fresh mortar when utilized waste clay brick tended to decrease with an increase in the percent of replacing. That result of the flow depending on the raw material and manufacturing process in addition to the irregular shape of waste aggregate which are often angular shape and high water absorption even if pre-soaking or adding extra water [14]. Utilizing waste glass as a partial replacement of sand led to decreasing the rate of the flow by 10% and 18% for 10% and 20% replacing respectively. The tendency of the flow to decrease when increases the ratio of waste glass can be attributed to the poor geometry of waste glass led to a decline in the fluidity of the fresh mortar and reduction of fineness modulus [24]. The mix containing waste clay bricks and waste glass demonstrated a reduction of 13%. Polypropylene fiber has a negative impact on the flow property, the higher reduction in flow rate given by mix R7 (41%) as regarded to control mix (R1). The flow rate was decreased by 32% for R7 comparing with the same mix but without fiber (R6). This behavior may be due to the fresh mortar plasticity that is restricted by volume increasing of fiber addition making a reduction in flow rate [25].

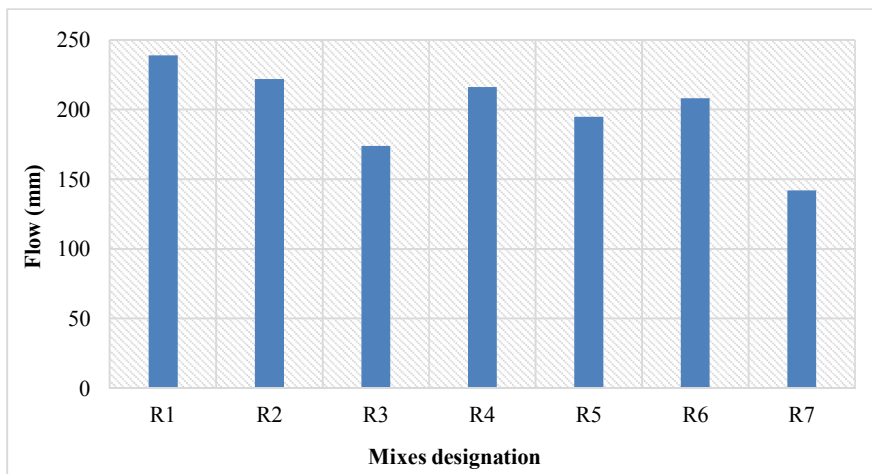


Figure 4. Average flow for fresh mortar mixtures

Table 5. Results of mortar mixtures for different tests

Mix designation	R1	R2	R3	R4	R5	R6	R7	
Flow (mm)	239	222	174	216	195	208	142	
Density Kg/m ³	2293	2109	2219	2172	2160	2180	2211	
Weighting loss %	200 °C	5.9	4.8	4.4	6.6	5.4	6.2	6.7
	400 °C	7.9	8.3	8.6	7.7	7.5	8.9	8.3
	600 °C	9	10.2	10.1	8.8	6.6	10	9.7
Compressive strength (Mpa)	24 °C	50	42.2	50.8	42.3	37.5	51.7	48.9
	200 °C	43.7	38.8	39.6	43.5	45.8	48.9	46.6
	400 °C	34.3	37.2	40.6	42.1	29.3	44.7	39.3
	600 °C	23.1	22.8	25.0	31.4	37.8	37.1	24.5
Flexural strength (Mpa)	24 °C	5.00	4.45	4.56	4.53	4.17	4.61	4.89
	200 °C	4.50	3.93	4.50	3.37	3.40	4.34	4.16
	400 °C	1.66	1.85	2.59	2.81	2.50	2.39	1.94
	600 °C	0.39	0.56	0.22	1.12	2.08	1.4	0.96
Water absorption (%)	24 °C	9.09	6.63	6.93	6.70	10.41	11.45	5.37
	200 °C	9.11	6.64	7.51	6.52	10.70	10.78	6.24
	400 °C	11.81	6.70	8.09	7.82	12.18	12.71	8.32
	600 °C	13.57	8.54	9.41	9.40	13.50	13.98	10.06

3.2. Density

Table 5 and Figure 5 presented the fresh density of mortar, the density of the reference mix (R1) was 2293 kg/m³. Utilizing waste clay bricks led to lowered density by 8% for 10% and 3.2% for 20% replacing as comparing with the control mix. The density of waste clay bricks was lesser than natural sand on the other hand with increasing percent of replacing the density of fresh mortar will be comparable to control mix due to the filling pores by physical effect and pozzolanic activities [26]. The fresh density of mortar decreased by 5.2% and 5.8% for 10% and 20% replacing natural sand with waste glass respectively and that may be attributed to the lower specific gravity of the waste glass regarding natural sand which is approximately 14.8% lower than sand [24]. The density of combination mixes consisted of more than one type of recycled materials was depending on the materials used itself. The mix R6 has been decreased density comparing with the control mix (R1) by 4.9%. Polypropylene fiber adding has a very slightly increased in mortar density as regarding the same mix without polypropylene fibers. The micro voids have reduced the orientation and the volume of calcium hydrated by constrained crystalline calcium hydrated to growth due to fiber ability, interfacial transition zone was denser as regarding the same mix without polypropylene fibers [27].

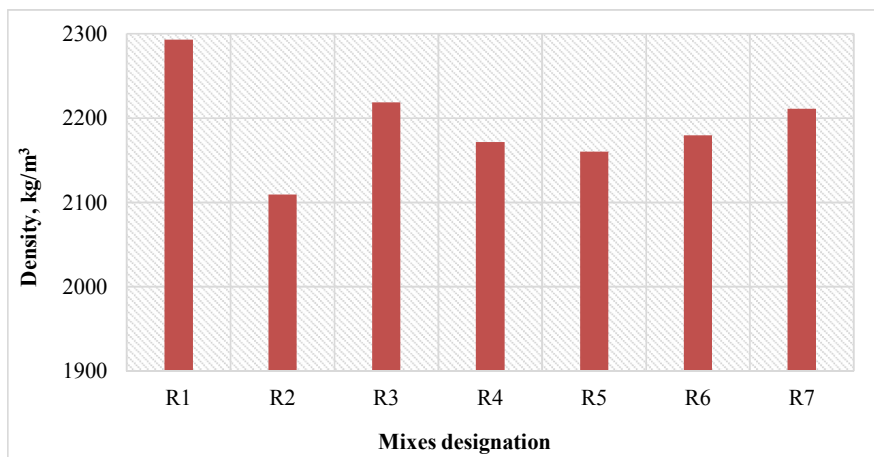


Figure 5. Density for fresh mortar mixtures

3.3. Weight Loss

The difference between the weights of the sample before and after exposure to heating was weight loss. Table 5 and Figure 6 illustrated the effect of different temperatures 200, 400, and 600 °C on the weight of the mortar. Weight losses, in general, was increase with rising temperature because of mechanical properties changing due to water evaporating in C-S-H [27]. The results were indicated the higher reduction occurred at 600 °C for all mixes comparing

with other temperatures. At 200 °C the replacing 20 waste clay bricks showed the minimum percent of loss weight 4.4% as compared with the same percent of replacing at 24 °C, while with increasing temperature the weight loss increased for 10% and 20% replacing. The weight loss began with the loss of free water in cement paste and absorb water in recycled aggregate with increasing temperature chemically bound water that presented in calcium silica hydrate resulting by the pozzolanic reaction of waste clay brick aggregate start to dehydrate [28]. Replacing 20% of waste glass showed the lowest result for weight loss by 5.4, 7.5, and 6.6% comparing with control mixes at 200, 400, and 600 °C respectively. While, 10% replacing the waste glass with normal fine aggregate presented the weight loss lowered by (6.6, 7.7, and 8.8%) at 200, 400, and 600 °C respectively comparing with normal mixes at same temperatures. The losing weight in the mixture that having waste glass aggregate due to the loss of free water in capillary pores while at a high temperature more than 400 °C return to dehydration of calcium silicate hydrated [29]. The combination mix of waste clay bricks with waste glass replacing natural sand has presented a reduction in weight by 6.2, 8.9, and 10% at 200, 400, and 600 °C respectively. Polypropylene fibers adding in the mixture does not affect losing weight property where there is no relationship between the evaporation water in mortar and fibers [30].

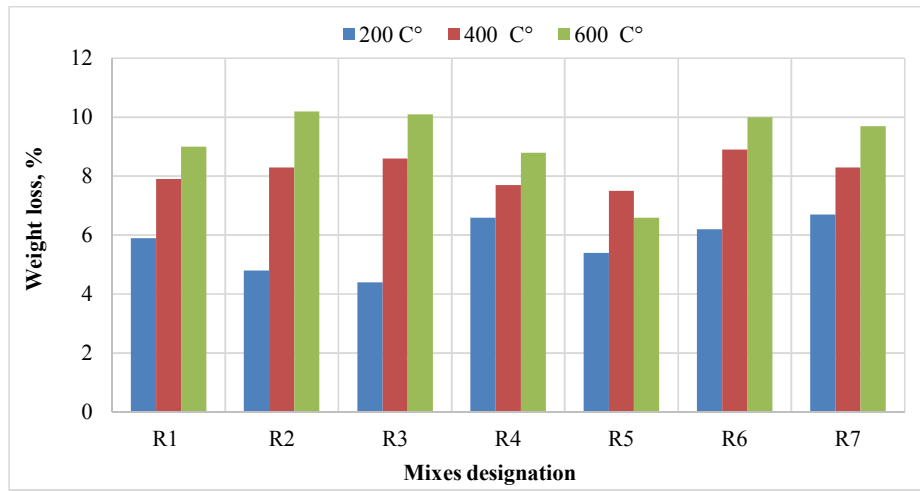


Figure 6. Weight loss values for mortar mixtures at different temperatures

3.4. Compressive Strength

Table 5, and Figures 7 to 10 presented compressive strength results. At room temperature (24 °C) for replacing normal sand with 20% recycle clay bricks and for a mixture that having 10% waste clay bricks with 10% waste glass compressive strength was improved by (2 and 3.5) respectively comparing to the control mix. While the reduction was 15.4% and 25% for 10% and 20% replacing the waste glass with natural sand respectively. Whereas, the decrease in compressive strength results may be caused by the lack of adhesive strength between the cement paste and surface aggregate (waste glass) because of the smooth surface of the glass which led to weakening bonding. Polypropylene fiber adding (R7) led to lowering compressive strength by 5.4% as comparing with the same mixture but without fibers (R6). The reduction in compressive strength returned to a lack of bonding between cement paste and fibers and that could help to propagate micro- cracks [31].

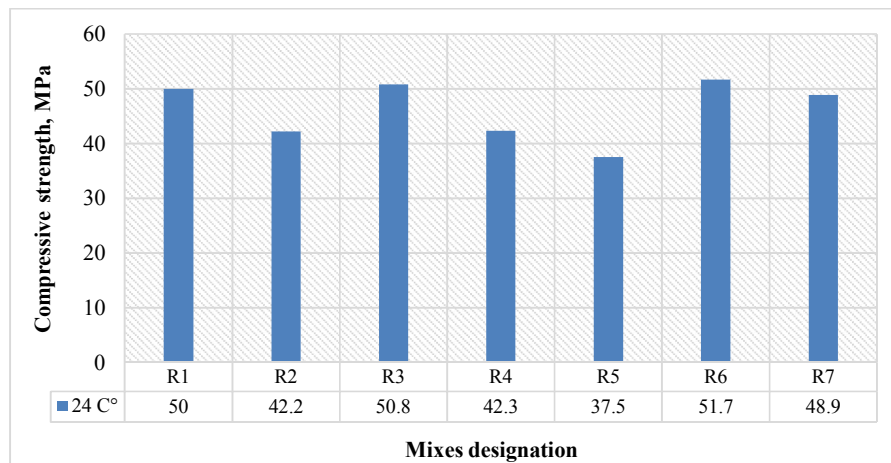


Figure 7. Compressive strength results at 24 °C

At 200 °C the reference mixture (R1) presented a reduction in compressive strength by 13% and that could be due to mortar dehydration by excluded free water and effected badly on mechanical properties. For waste clay bricks replacing fine aggregate, the compressive strength appeared reduction by 11.2% and 9.3% for 10% and 20% respectively. Most of the damage in the mortar at 200 °C resulting in the elimination of free water in addition to the beginning dehydration of calcium silicate hydrated [32]. Utilizing 20% waste glass for replacing sand showed improvement in compressive strength by 5% at 200 °C. The compressive strength increased by 12% and 7% for a mixture that has 10% waste clay bricks in addition to 10% waste glass, without and with 1% Polypropylene fibers (R6 and R7) respectively. The mixture having waste glass showed higher strength than normal mix especially at high temperature and this behavior may be since the free water hold over in the mix is dissipated at high temperatures much readily in mixes containing glass. In addition to the inability of glass to absorb water [17]. By adding polypropylene fiber at 200 °C the surface temperature of the sample higher than the inside and that led to restricted melting fiber (160 °C). The compressive strength reduced by 4.7% compared with the same mix without fibers (R6) that may be because of voids due to fiber incorporated and less bonding between cement paste and polypropylene fiber.

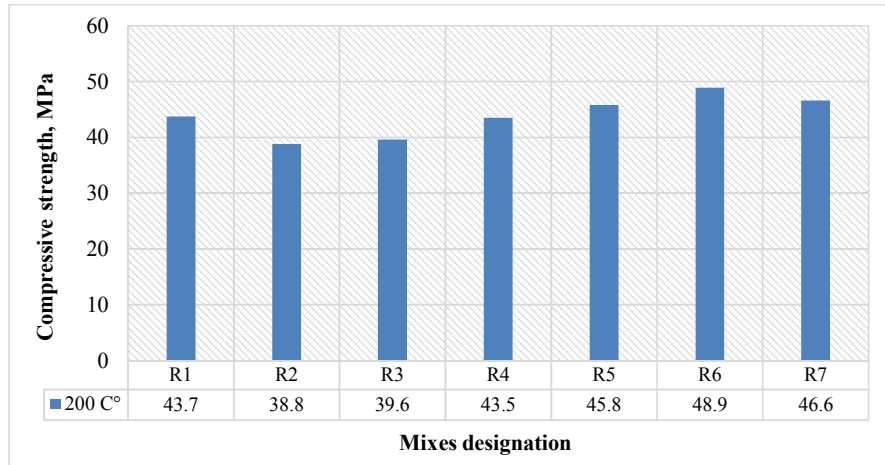


Figure 8. Compressive strength results at 200 °C

Compressive strength was reduced with increasing temperature to 400 °C by 31% for the control mix comparing with the same mixture at normal temperature 24 °C. The lowering in strength refers to dehydration of C-S-H and ettringite and started generally at 300 °C. Utilizing waste clay bricks as partial sand replacing in mixtures with 10% and 20% led to enhance compressive strength by 8, and 18% respectively. Regarding the waste aggregate type used, clay bricks aggregate shows improvement in compressive strength and that can be attributed to many reasons. First, with increasing temperatures of more than 400 °C, the nature of clay bricks made them stronger and stiffer by twice. Second, at high temperatures, the unhydrated cement paste may undergo additional hydration [17]. Whereas, compressive strength indicated to increased more than the control mixture by 22% for 10% waste glass but with increasing percent of replacing to 20% the compressive strength reduced. The mixture consisting of waste glass with waste clay bricks (R6) as replacing for sand was higher compressive strength by 30.3% as compared with the control mix at 400 °C. At 400 °C polypropylene fiber was melted leaving behind voids that affected adversely compressive strength.

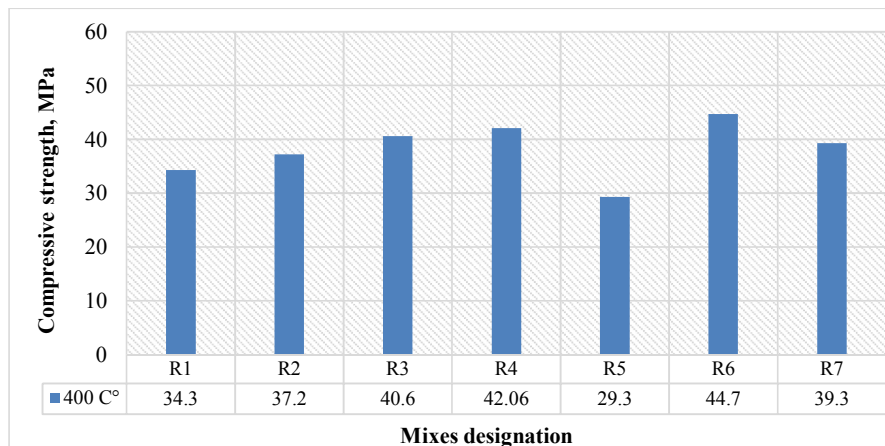


Figure 9. Compressive strength results at 400 °C

With increasing temperature to 600 °C, compressive strength showed a huge reduction of more than 53% for reference mixture (R1) as regarding the same mixture at room temperature. Micro cracks were formed in a mortar with increasing the temperature of the oven from 400 °C to 600 °C due to calcium hydroxide dihydroxylation. Compressive strength led to reduction because of weak bonding between cement paste (hydration products) and fine aggregate. The higher compressive strength for waste clay bricks aggregates depending on the higher content used. For 20% replacing the compressive strength was higher than the normal mix at the same temperature (600 °C) [32]. Waste clay bricks consider stable and one of the best aggregate which can use for resist fire and high temperatures [12]. For utilizing waste glass as partial replacing of fine aggregate compressive strength increased by 40% and 63.6% for 10% and 20% respectively as compared with control mix at 600 °C. The combination mixture consisted of 10% waste clay bricks with 10% waste glass observed higher compressive strength than the control mix by 60.4%. The compressive strength for mixture having polypropylene fiber reduced by 33.8% as compared with the same mixture without fibers that due to voids in mixture results melting fibers.

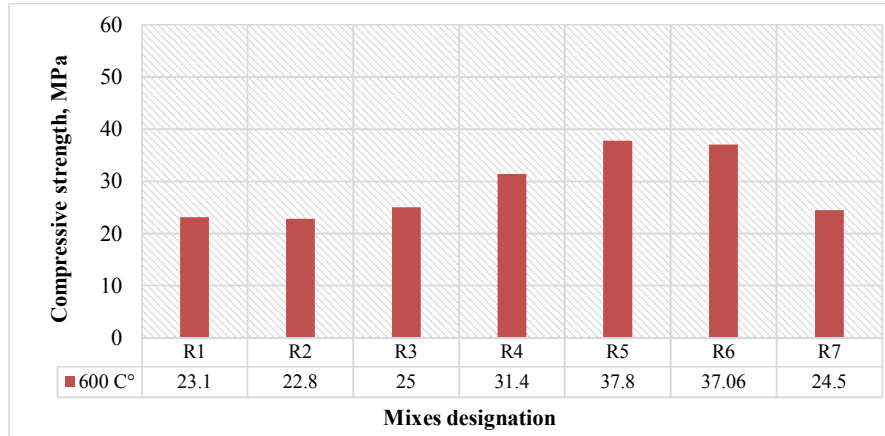


Figure 10. Compressive strength results at 600 °C

3.5. Flexural Strength

It was clear from the results presented in Table 5 and Figures 11 to 14, all flexural strength values at an ambient temperature lowered than the reference mix (R1). The results demonstrate that utilizing waste clay bricks aggregate led to a lowering in flexural strength by 11% for 10% and 8.8% for 20% replacing, which may be due to the microcracks in the interfacial transition zone and few internal voids in the waste clay bricks aggregate. That could be due to the method adopted for preparing waste aggregate in addition to the effect of the particle size distribution of waste material and characteristics of clay bricks like strength and roughness [3]. Through the increase in the percent of replacing of waste glass from 10% to 20%, flexural strength lowered by 9.4% and 16.6% respectively, and that may be due to change in properties of interfacial transition zone regarding normal mix in addition to the difference in densities between the normal aggregate (sand) and waste glass. The result of flexural strength lowered by 7.8 for a mixture that having waste clay bricks with waste glass (R6) comparing with the control mix (R1). By adding Polypropylene fibers flexural strength was improved by 6% for mix (R7) as compared with the same mix but without fibers. The initial cracks were restricted in mortar due to Polypropylene fiber's ability [33].

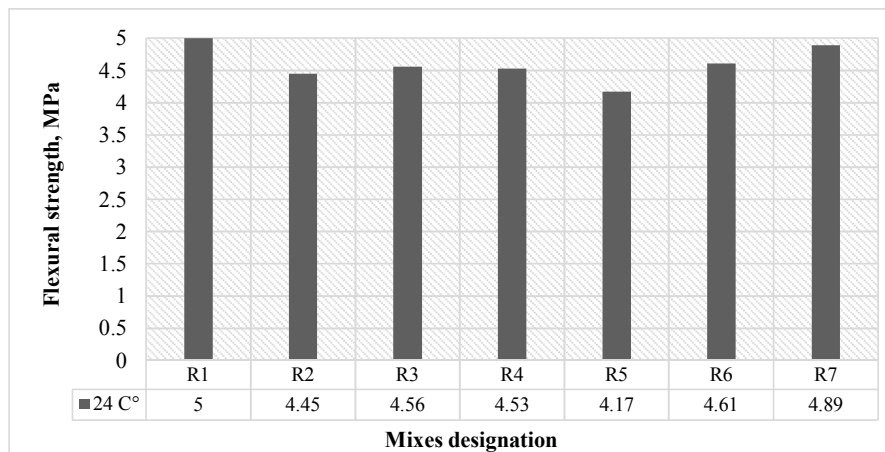


Figure 11. Flexural strength results at 24 °C

At 200 °C, the flexural strength was showed a reduction by 10% as compared with the same mix at normal temperature. In general flexural strength was higher sensitive than compressive strength because of micro-cracks in samples as regarding same specimens under ambient temperature. The results for adapting waste clay bricks aggregate were comparable with the normal mix at the same temperature that due to the good bonding behavior of waste aggregate with paste at 200 °C. Incorporated waste glass for replacing fine aggregate harms flexural strength by 25.1% and 24.4% for 10% and 20% replacing respectively. This reduction back to evaporate the pore water (25-105 °C) and dehydration of ettringite and calcium silicate hydrated at 105-300 °C [34]. The combination mix that having waste clay bricks and waste glass (R6) was reduced flexural strength by 3.5% as compared with the reference mixture at 200 °C as shown in Figure 9. Polypropylene fibers were started to melt at 160 °C, the surface of specimens was reached to 200 °C but the inside specimens less than the degree of melting therefore the flexural strength was reduced due to less bonding between paste and fiber.

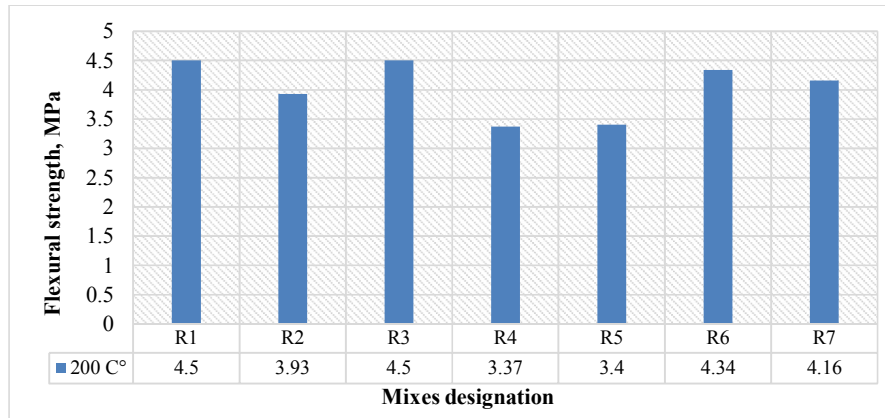


Figure 12. Flexural strength results at 200 °C

When the temperature of the oven reaches 400 °C, flexural strength was illustrated lowering by 66.8% as comparing to the control mixture at ambient temperature. Calcium hydroxide presented dehydroxylation after 300 °C for that, microcracking was happened and affect adversely flexural strength. Waste clay brick aggregate showed higher flexural strength comparing with the normal mix at 400 °C by 11.4% and 56% for 10% and 20% replacing respectively and that may be for good bonding between waste aggregate and paste even though some waste particles smooth surface [35]. The calcium hydroxide $Ca(OH)_2$ in cement paste exposed to a sudden drop in temperature between 375 to 480°C and that led to decompose, with replacing natural sand with waste glass clearly enhance in flexural strength appeared by 69% for 10% and 50.6% for 20% replacing, and that agree with research [36]. The combination mixture (10% waste clay bricks with 10% waste glass) was showed enhancing in flexural strength by 44% as regards the reference mix at 400 °C. The flexural strength was reduced at 400 °C for a mixture that having Polypropylene fibers due to melted and calcined fibers leaving behind voids that cannot stop crack propagation [30].

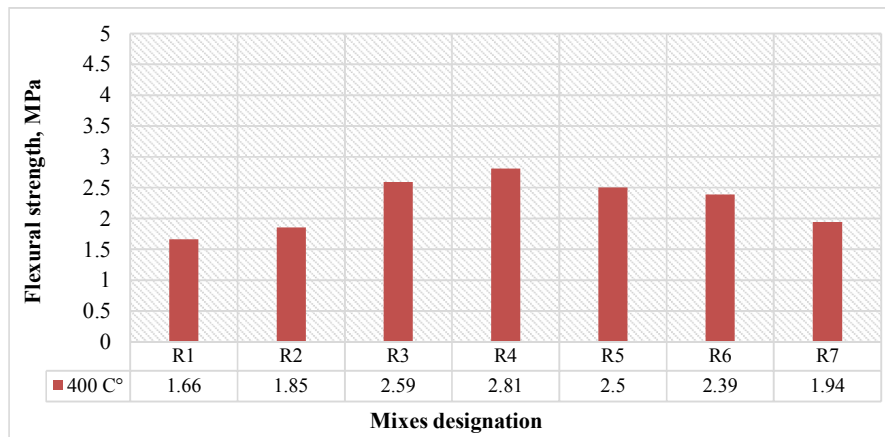


Figure 13. Flexural strength results at 400 °C

The flexural strength at 600 °C was collapsed, the reduction in strength reach to 92.2% as regards to reference mix at normal temperature. The dehydration of calcium silicate gel led to decreasing flexural strength at this stage. With increasing temperature to 600 °C the waste clay bricks losing a high percent of flexural strength due to microcracks resulting of dehydration of calcium silicate hydrated gels and that reduction depending on materials of clay bricks

itself [28]. On the contrary, the mixture with waste glass was dominant at high temperatures (600 °C). The flexural strength was (1.12 MPa for 10% and 2.08 MPa for 20% replacing considered 0.39 MPa at 600 °C for control mix), that is probably due to the high temperature near to the transition temperature of glass (560 °C) of soda-lime glass, the phenomena of transformation attitude of waste aggregate from “glassy to rubber” happened in mortar could able to enhance microcracks and pore structure of mixture [37]. The flexural strength was presented improving by replacing natural sand with waste aggregate (waste clay brick with waste glass). The waste aggregate was more responsive to high temperatures than normal aggregate as shown in Figure 14. The flexural strength was lowered by 31.4% for the mixture having 1% Polypropylene fibers (R7) as comparing with the same mixture without fiber (R6) at 600 °C. The voids were created by melting Polypropylene fibers affect adversely on flexural strength property.

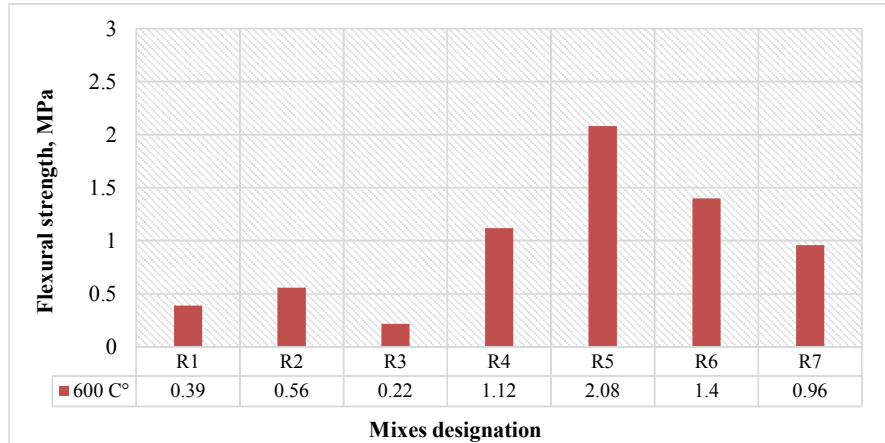


Figure 14. Flexural strength results at 600 °C

3.6. Water Absorption

Generally, with increasing temperature water absorption was increased. The control mix R1 showed an increase in water absorption by 30% at 400 °C and 49.2% at 600 °C and that could be a high percentage of porosity due to hydration products decompose with increasing temperature [38]. The waste clay bricks aggregate observed clearly a reduction in water absorption compared with the control mix at different temperatures by 27, 27.1, 43.2, and 37.7% for 10% replacing at 24, 200, 400, and 600 °C respectively, and 23.7, 17.5, 31.4, and 30.6% for 20% replacing at 24, 200, 400, and 600 °C respectively as shown in Figure 15. This reduction in water absorption competing with the good quality of materials used for the construction of refractory clay bricks [39]. Waste glass aggregate has the same properties (physical) as sand but it presents a lower percentage of water absorption [24, 40], for that the result appeared low rate of water absorption comparing with control mix. For 10% replacing waste glass aggregate the water absorption reduced by 26.3, 28.4, 33.7, and 30.7% at 24, 200, 400, and 600 °C respectively. While for 20% replacing the results were comparable to the control mix at different temperatures. The mixture having waste clay bricks and waste glass illustrated increasing in water absorption in normal temperatures comparing with the control mix. The percent of water absorption increased clearly at 400 °C and 600 °C. With increasing temperature, the mixture that having fibers (polypropylene) showed increased in water absorption and that may be because of cracks propagation due to melting fibers [4, 30].

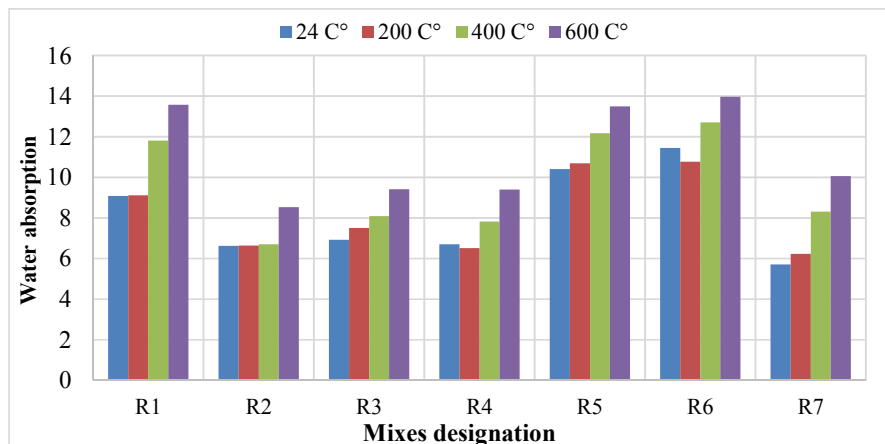


Figure 15. Water absorption results for mortar at different temperatures

4. Conclusions

Depending on the study undertaken here, the findings can be drawn:

- The fresh mortar was presented decreasing inflow with increasing percent of replacing normal fine aggregate with recycling materials. The waste glass incorporated showed higher flow than waste clay bricks at 20% of replacing while the fibers adding was led to reducing the flow rate;
- The density for mortar decrease with utilizing waste materials. The waste glass mixture at 10% illustrated a higher density than waste clay bricks;
- By increasing the temperature of the oven the weight loss was increased. In general, the waste glass showed higher resistance for weight loss at different percentages and temperatures than waste clay bricks;
- The compressive strength was decreased with increasing temperature for all mixtures. The waste clay bricks 20% showed higher strength than the other mixture at 24 °C. The waste glass and the combination mixture at 200 °C and higher temperatures presented improve in compressive strength than the control mix at the same temperatures;
- At ambient temperature, the flexural strength for the reference mixture was a higher value as compared with other mixtures. The flexural strength for the mix that having 1% Polypropylene fiber was comparable to the control mix. At 200 °C the mix that adapting waste clay bricks aggregate was comparable with the control at the same temperature. The flexural strength at 400 °C was showed improving by 56% for 20% waste clay brick and 69% with 10% waste glass, as well all combination mixes illustrated higher strength than the control. The waste glass showed higher flexural strength at 600 °C as regarding control in addition to all combination presented higher strength;
- With increasing the temperature the water absorption was clearly increased. The utilizing of waste materials as partial replacing of natural sand was led to lowering the percent of water absorption as regarding reference mix at different temperatures. By adding 1% polypropylene fibers the percent of water absorption was lowered as compared with the same mixtures without fiber at different temperatures.

5. Declarations

5.1. Author Contributions

Conceptualization, Z.A., and S.Q.; methodology, Z.A.; investigation, A.S.; resources, S.Q.; data curation, Z.A.; writing—original draft preparation, Z.A.; writing—review and editing, S.Q.; supervision, S.Q. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in article.

5.3. Funding

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5.4. Acknowledgements

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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