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INVESTIGATION OF USING WASTE GLASS POWDER (WGP) AS A PARTIAL NATURAL SAND REPLACEMENT IN CONCRETE FOR A POTENTIAL USE IN IRAQI CONSTRUCTION FIELD

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Abstract

Glass waste contributes about 5% of the total solid waste generated worldwide that ends up in landfills without recycling resulting in considerable environmental harm. In this research, Waste Glass Powder (WGP) was studied to be used as a supplementary material substituted with sand in the concrete mix. The concrete mixes were prepared by replacing the natural sand with WGP in weight proportions of 10% to 50%, with a 10% increment to examine the mechanical effect of WGP addition on concrete performance in the fresh and hardened status. The concrete mixes were tested to evaluate the compressive strength for curing ages 7, 14, 21, 28, 56, and 90 days. Splitting tensile strength was also tested for curing at ages of 7, 14, 21, and 28 days. The obtained results showed a notable decrease in workability value for all concrete mixes with WGP addition. Also, the addition of WGP decreases the compressive strengths of all concrete mixes. However, the WGP enhanced the splitting tensile strength by about 12%. It has been concluded that the WGP can be used as a substituted material replaced with sand up to 30%, which was the optimum replacement ratio based on the Iraqi required specifications. By using this ratio, the compressive strength was decreased by 18% at 28 days of concrete curing age.

Keywords:

Waste Glass Powder (WGP);
Concrete mix design;
Compressive strength;
Green concrete.

1 Introduction

Due to the rapid development in the construction field, the demand for construction materials has experienced a significant jump in recent years all around the world. Concrete is considered the most consumed material that is being used in construction because of its durability, strength, and versatility; and its demand is increasing day after day due to population expansion[1]. As it is well known, the concrete mixture consists of four main compositions; cement, sand, and gravel mixed with water. The ratio of each composition is calculated based on the required strength, in Iraq the most used ratio in construction is 1:1.5:3 and 1:2:4 [2]. Based on these mix design ratios, it can be observed that the sand ratio is at least one and a half times the amount of cement.

In recent years the production of cement has increased significantly and has become the third largest source of emission of carbon dioxide after fossil fuels and land-use change [6]. Globally, about 4.2 billion tons of cement is produced annually to cover the world's demand [3]. Similarly to the word rapid increase, Iraq's cement production has also increased [8]. According to Global Cement [4], the production of Iraqi cement reached to 22 Mt/yr at the end of 2014. It is also expected that Iraq's cement demand will increase further and reach up to 30 Mt/yr in 2021. This production comes from five main factories that are distributed around all the area of Iraq on eight main governorates; Al-Anbar, Kirkuk, Mosul, Najaf, Muthana, Babil, Sulaimaniah, and Kerbala. The maximum production amount is produced by Sulaimaniah's factories as can be demonstrated in Fig. 1 below.

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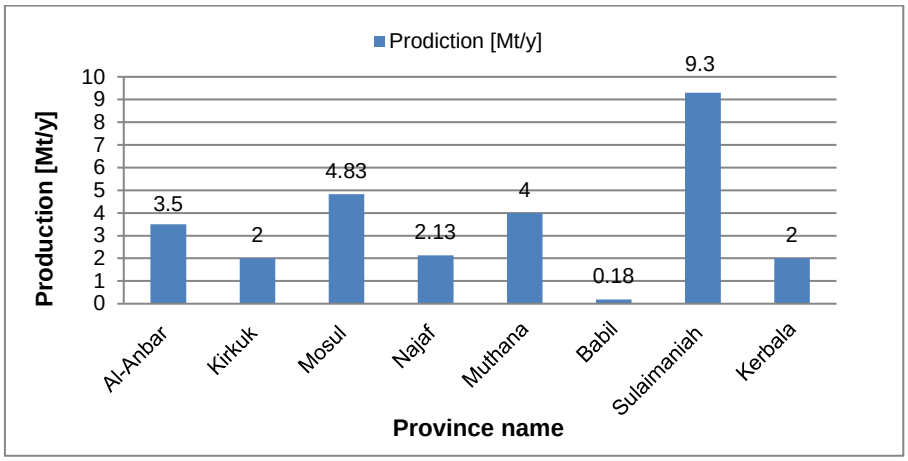


Fig. 1: Iraq cement production by province.

This enormous amount of produced cement will be turned into concrete to cover the construction demand in Iraq and this will pose an environmental concern to cover the demand for natural sand used in the construction industry. Therefore, finding an alternative source of sand that can reduce the dependence on natural sand can promote an environmental solution. According to recent literature, waste glass powder has shown a significant role to be used as supplementary construction material replaced partially with cement and/or sand [5].

End-use glass represents 5 percent of global municipal solid waste. According to the World Bank organization[6], the world produces about 2.01 billion tons of municipal solid waste (MSW) with an expectation to reach around 3.4 billion tons in 2050 (see Fig. 2). The study shows that Middle East countries are expected to duplicate solid waste growth in 2050. Consequently, due to the current solid waste management systems, dry waste will have notably grown to a risky level that might dominate factors of high and risky pollutants more than other factors.

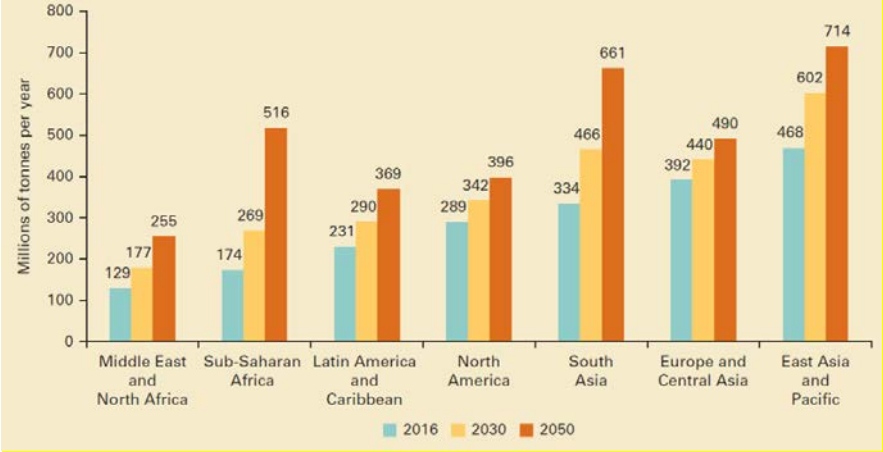


Fig. 2: Anticipated waste generation by region [Annual million per ton].

In the last decades, countries have started recycling solid waste either food and green waste and/or dry waste. Different technologies have been adopted as sustainable approaches for solid waste management. However, these approaches have targeted glass to a limited extent. Glass involves about 5 percent on average of the total municipal solid waste globally (As can be illustrated in Fig. 3). Originally, three main ingredients that form shapeless glass, are lime or calcium oxide, Sodium carbonate, and high content of silica. These unique glass compositions make end-use glass an appropriate raw supplementary material [7][8][9].

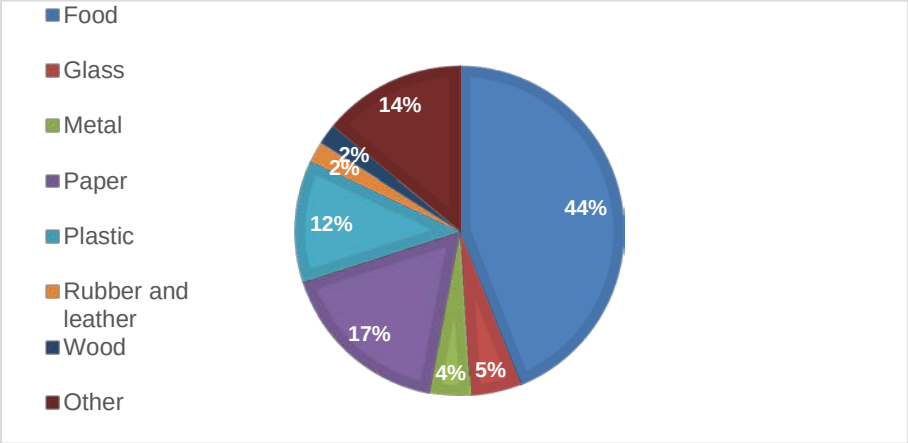


Fig. 3: Global waste composition percentage[6].

Some studies demonstrated that glass might promote alkali–silica reaction (ASR) and/or pozzolanic activity in substituted materials. In addition, findings showed soda-lime glass particles has less than 0.6 mm dimension with concrete produce minimal ASR. While ASR activity occur in larger particles due to micro cracks and not due to glass-paste interface[10]. This article aims to investigate the soda-lime glass mortar effects on concrete performance, and how it can be a sustainable solution for the end-use glass in Iraq by accommodating it with concrete mixture.

Solid waste can be used as a replacement for some main concrete raw materials. In Iraq, solid waste management is classified as a growing issue in most of Iraq's urban areas[11]. This problem has been severely aggravated as a result of absence of proper solid waste management. Therefore, utilizing those waste materials in green concrete production can promote environmentally sound solutions. This study aims to find the potential use of such waste glass in concrete blend by adopting green concrete concept. Glass powder waste material will be investigated to be used as a replacement of natural sand in concrete mix design. In Iraq research trends, no study has been done before to test and evaluate the use of Glass powder as sand replacement in green concrete characteristic mixture. Utilizing the waste glass in concrete mix will provide two valuable solutions. The first is that using the waste glass will reduce the environmental hazard caused by dumping the waste glass into landfill. While the second solution is that using the waste glass as a partial replacement for sand will reduce the amount of sand used in concrete which is considered a depletable natural resource.

2 Characteristics of used concrete materials

Concrete design mixture consists of four main materials, cement, sand, gravel, and water. The ratio of each composition is varied depending on the mixture design to achieve the required strength[12]. The sand used in this particular study was partially substituted with crushed glass powder. The substitution ratio was within the limit of 10% to 50%. Below are the main materials that have been used in this research.

2.1 Cement

As mentioned, the biggest production of cement in Iraq is produced by Sulaimaniah's factories. MASS Ordinary Portland Cement (OPC) was used in this research and is manufactured by MASS group company / Bazian plant in Sulaimaniah province. This brand of OPC is certified cement with ISO 9001:2015. Table 1 shows the chemical properties of MASS ORC with reference to Iraqi standards specifications number 5 that has been issued on 1985 by Central Organization for Standardization and Quality Control (COSQC) [13].

Table 1: the chemical properties of MASS ORC.

#	Property	Unit	MASS cement	COSQC
1	MgO	%	4.3	Max 5
2	Insoluble residual	%	1.2	Max 1.5
3	Loss of ignition	%	3.8	Max 4
4	SO3 when CA3 - Less than 5% - More than 5%	%	 2.4 2.55	 Max 2.5 Max 2.8

2.3 Coarse and fine aggregate

The coarse and fine aggregate that has been used in this research is natural river aggregate which is widely used in Iraq's concrete mix design, the photos of fine and coarse aggregates are shown in Fig. 4. According to Iraq's specification of construction materials (specification number 30 in 1981)[13], the aggregate can be classified as either coarse or fine based on the remaining or/and the passing from the sieve size of 4.75 mm. The coarse aggregate is the aggregate remaining on the sieve size of 4.75 mm, whereas the passing aggregate can be classified as fine aggregate.

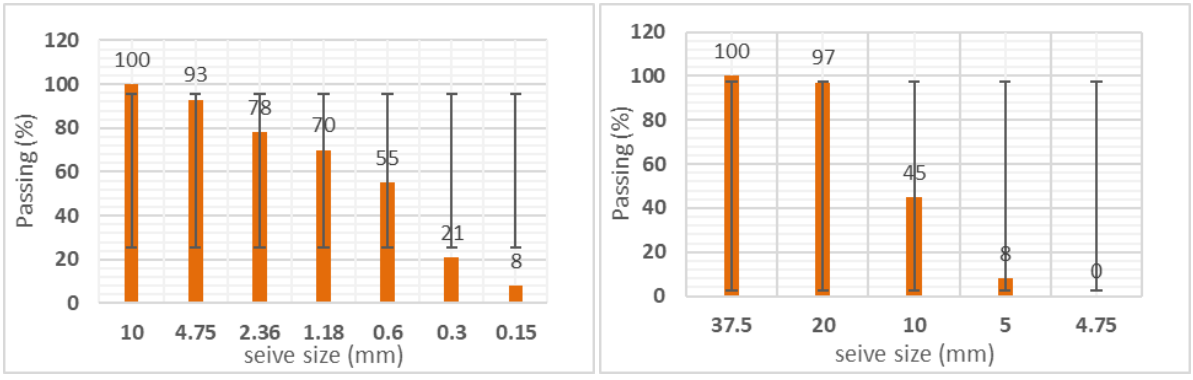


Fig. 4: photos of coarse and fine aggregates used in this study.

Both aggregates were tested to determine the physical properties, the results were reported and shown in Table 2. In addition, the gradation test was conducted and the results are presented in Fig. 5.

Table 2: Fine and aggregate physical properties.

	Water absorption	Specific gravity	Fineness modulus
Fine aggregate	1.20%	2.55	2.7
Coarse aggregate	0.9%	2.67	5.3



a) Gradation test results of fine aggregate. b) Gradation test results of coarse aggregate.

Fig. 5: Gradation test of used aggregate.

2.4 Water

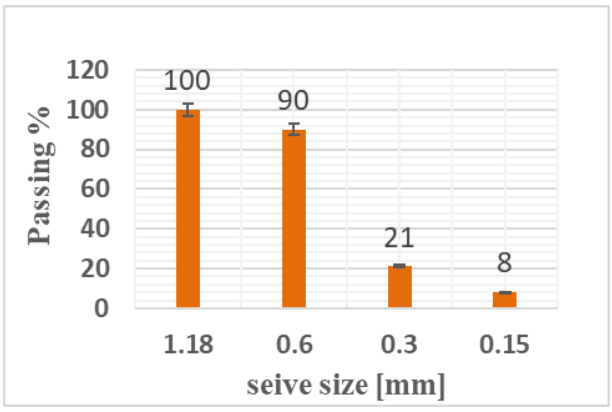
The water used for all concrete experiments was tap water, and is complied with Iraqi potable water specifications[14]. Moreover, TDS, pH, and turbidity were tested, and the results were 750 mg/l, 6.8, and 4 NTU, respectively.

2.5 Waste glass powder (WGP)

Waste Glass powder (WGP) has been prepared by crushing manually raw bottles of Soda-lime glass (see Fig. 6, photo c) that has been collected from nearby dumpsites before grinding it by using a ball mill (see Fig. 6, photo a) to get the final product as can be seen in (Fig.6, photo d). In addition, a gradation sieve test has been conducted (see Fig. 7, photo b) to get the required size which was within the range (0.15 – 0.6 mm) as well as to eliminate the effects of poor graded aggregates impact on the experiment.



a) Ball mill instrument.



b) Gradation test of grinded glass-powder.



c) Crushed glass before grinding.



d) Grinded glass powder.

Fig. 6: Preparation stage of waste glass powder (WGP).

3 Concrete mix design

The weight method was used to design the concrete mix design with 1:1.5:3 proportions, cement, sand, and gravel, respectively. The weight of cement used in this research was approximately 390 kg/m^3 and the water-to-cement ratio (w/c) was within the range (0.45 – 0.55). The concrete samples were prepared by replacing the sand with waste glass powder (WGP) with a weight substitution rate of 10% to 50% with 10% of augmentation in each trial. Table 3 shows the mix design proportion of each material used in this research.

Table 3: Proportions of mix content for 1 m^3 of concrete.

	Cement [Kg]	Fine aggregate [Kg]	Coarse aggregate [Kg]	Water [Kg]	W/C	Waste Glass Powder (WGP) [Kg]
0% (MC)	390	585	1170	188	0.48	0
10% (MWGP)	390	526.5	1170	195	0.5	58.5
20% (MWGP)	390	468	1170	200	0.51	117
30% (MWGP)	390	409.5	1170	205	0.52	175.5
40% (MWGP)	390	351	1170	210	0.53	234
50% (MWGP)	390	292.5	1170	215	0.55	292.5
(MWGP) – Mix with Waste Glass Powder (MC) – Mix Control with zero add						

4 Research methodology

The methodology process adopted in this research can be summarized as shown in Fig. 7. As mentioned before, silica glass bottles were collected from a nearby dump sites. Then, those glass bottles were crushed and ground by using a ball mill to produce the waste glass powder (WGP) that have been sieved to get the desired diameter. Concrete mix designs have been designed based on ASTM standard [15]. WGP was used as a sand replacement with replacement ratio from 10% to 50%. Cylinder concrete specimens with a size of 150 mm diameter and 300 mm height were casted and cured up to 90 days. In addition, all experiments to measure the compressive strength and workability were conducted according to ASTM standards C39 and C143, respectively[16][17].

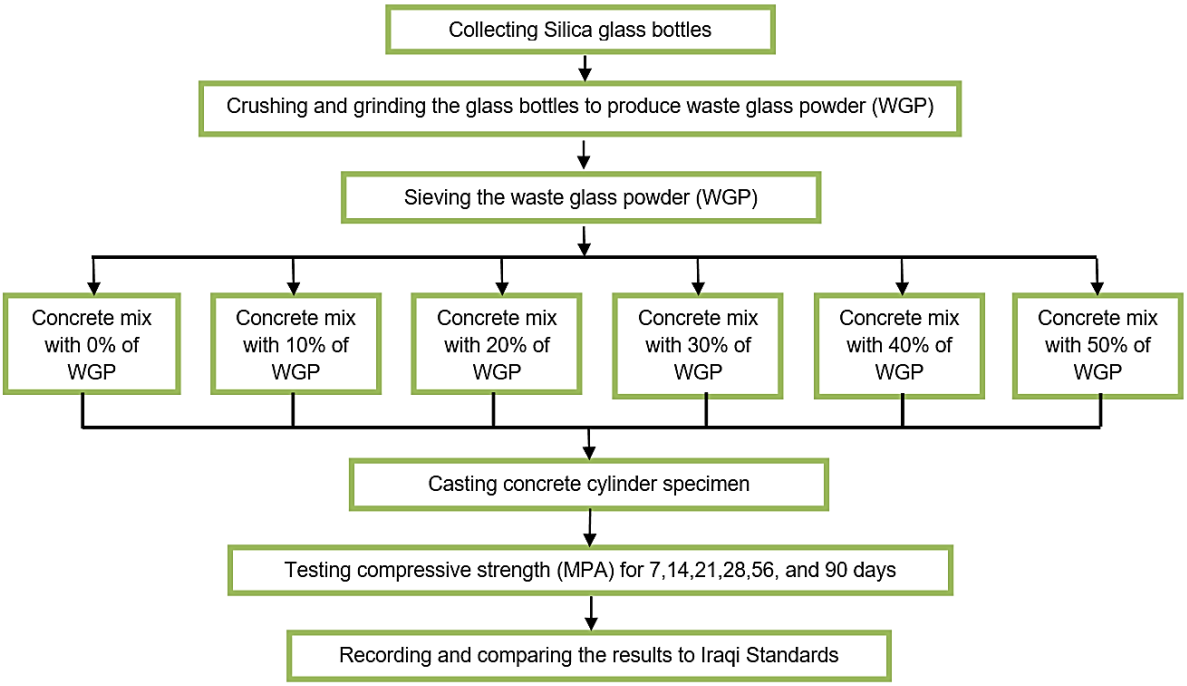


Fig. 7: Flow chart of research methodology

5 Results and Discussion

There are few tests that can be performed on concrete on both fresh and hardened states to examine the characteristics and the quality of concrete. However, due to the many studies that have been conducted to assess concrete on those tests, only workability and compressive strength will be examined in this research to assess the effect of WGP substitution with sand in concrete admixture.

5.1 Workability

According to ASTM-C143 [17], slump test was conducted at all portions of concrete mixes and the result were reported as can be demonstrated in Table 4. A considerable change was observed in a slump test results due to WGP addition that have led to a noticeable decrease in slump test value as long as the WGP proportion increased. The decrease of slump test value due to WGP addition were also reported in some literature. Khan et al. [1] in their study reported that utilizing the waste glass powder as supplementary material with partial replacement with cement has led to a substantial decrease in slump test results. This effect was also reported by Harrison et al. [5] in their findings on using recycled waste glass as aggregate in cement-based materials.

Table 4: Slump test results on fresh state concrete.

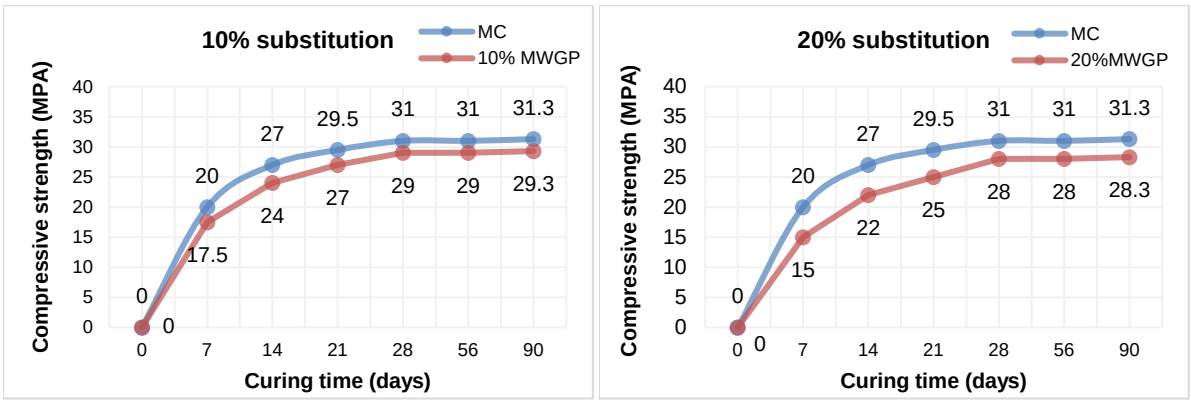
Admixture design proportion	Slump test value [mm] before adjusting the water ratio	Added water to adjust the slump value [Kg]	Slump test value [mm] after adjusting the water ratio
0% (MC)	105	0	105
10% (MWGP)	92	7	107
20% (MWGP)	78	12	106
30% (MWGP)	64	17	106
40% (MWGP)	53	22	108
50% (MWGP)	41	27	109

In the case of using the WGP as a supplementary material in the concrete mixture, most of the published studies adopted a fixed water content ratio and consequently, the slump values were varying based on the substitution rate. Alternatively, in this study, the slump values were adjusted to achieve relatively constant workability conditions for all admixture proportions.

5.2 Compressive strength

Compressive strength is considered the most common and important test to evaluate the quality and durability of concrete[18]. In this research, the presentation of compressive strength test data were demonstrated as can be shown in Fig. 8, where each result of substitution rate has been presented in a separate graph highlighting the relation of results of the main mix concrete (which is considered a reference control mix of concrete (MC)) with the concrete mix of waste glass powder (MWGP). This kind of data presentation will permit the reader to easily observe the differentiation of results obtained between the main mix of concrete (MC) with the concrete mix of waste glass powder (MWGP).

Based on ASTM C39 specification[16], compressive strengths (fc) were calculated by using cylinder specimens with 300 mm length and 150 mm diameter that were tested in the compressive testing machine (see Fig. 9 – a and b). The molded concrete cylinders were cured and then submerged in clean and potable water as per ASTM standards while the tests are being conducted. The same ASTM standards recommended testing the cylinder specimens for test age of 24 h, (3,7,28, and 90 days), however, in this study concrete compressive strengths were tested for the test age of 7,14,21,28,56, and 90 days in order to examine the slight change in compressive strength behavior due to WGP addition.



a) b)

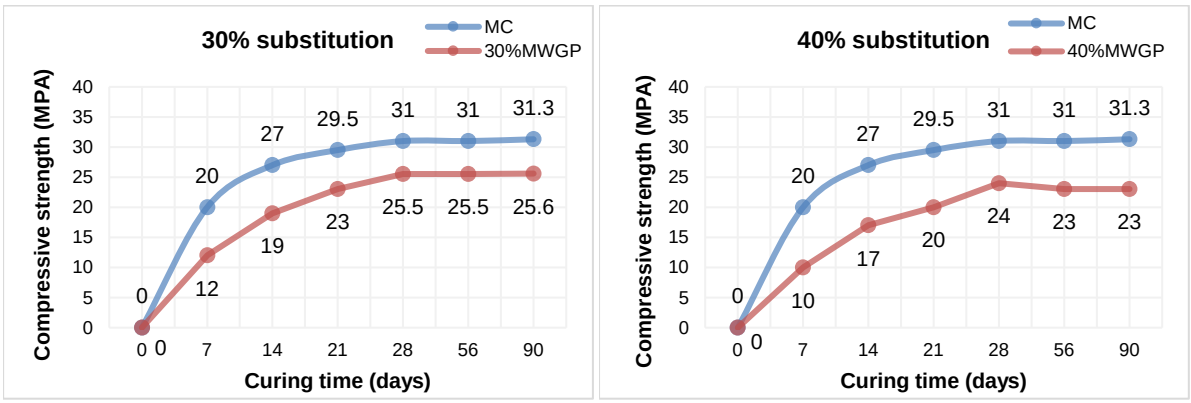


Fig. 8: Compressive strength of concrete containing various amount of WGP.



a) b)

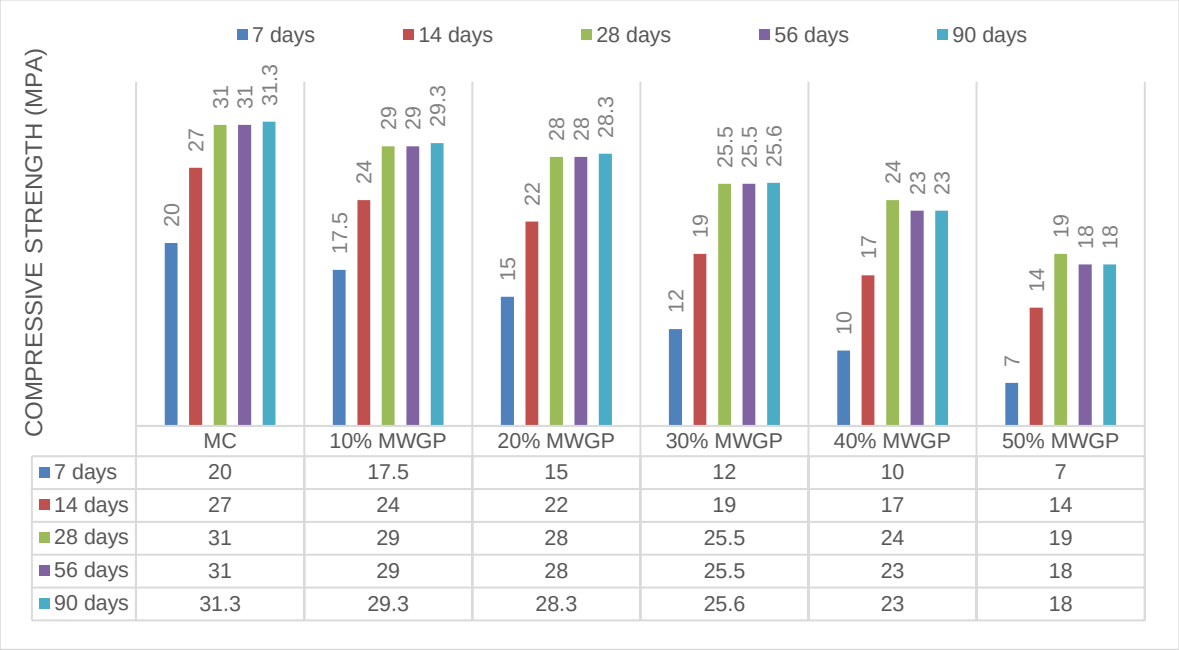
Fig. 9: a) Casted Cylinder specimen, b) Compressive strength machine.

Fig. 8 demonstrates the effects of MWGP on concrete compressive strength. The results showed a notable reduction in the concrete strengths for all concrete mix designs when WGP was added 10% to 50% of sand substitution, with a 10% increment in each trial.

There was a notable decrease in compressive strength value when 10% of WGP was used (see Fig. 8-a) during the first early 7 days of hardening, reaching 13%. This reduction slightly decreased notably between the age of 14 and 21 days, the compressive strength results decreasing reached to 11% and 8% for ages 14 and 21 days, respectively. However, for ages between 28 and 90 days, the compressive strength deterioration started to recover, and the reduction in compressive strength value reduced to 6% for those ages, showing a slight stability with 6% strength reduction in comparison with MC. Similar behavior has been observed in the second trial when 20% of WGP was used (as seen in

Fig. 8-b), but with a bigger decrease in compressive strength compared to 10% of WGP replacement. The compressive strength reduction values were reported for the ages of 7,14,28, and 90 days and the results were 25%, 19%, 10%, and 10%, respectively.

In comparison with 10% and 20% replacement, the loss in compressive strength values deteriorated much faster in the trials of 30% and 40% of WGP replacement, as can be seen in (Fig. 8-c and 8-d). In the 30% replacement trial, the reduction in compressive strength increased to 40%, 30%,18%, and 18%, for the ages of 7,14,28, and 90 days, respectively. Furthermore, in the 40% replacement trial, the compressive strength reductions were reduced to 50%, 37%, 23%, and 27% for the ages of 7,14,28, and 90 days, respectively.



	MC	10% MWGP	20% MWGP	30% MWGP	40% MWGP	50% MWGP
7 days	20	17.5	15	12	10	7
14 days	27	24	22	19	17	14
28 days	31	29	28	25.5	24	19
56 days	31	29	28	25.5	23	18
90 days	31.3	29.3	28.3	25.6	23	18

Fig. 10: Compressive strength at various ages.

The last trial was conducted by using 50% of WGP replacement (see Fig. 8-e). In this ratio, considerable loss was reported in compressive strength value. At the age of 7 days, about 65% reduction of the compressive strength was reported and about 48% at the age of 14 days. Moreover, for the ages of 28 and 90 days, the reduction in compressive strength values were reported as 39% and 42%, respectively.

Some recent studies have reported that the use of WGP in the concrete mixture has led to an aggravated deterioration of concrete strength during the early period of curing ages [1][19][20][21]. This also has been confirmed in this study, especially for high percentage rate for 40% and 50% of WGP replacement. However, during the prolonged ages of 56 days and 90 days, the compressive strength showed notable recovery, particularly for low and moderate percentage rates of WGP replacement that have been performed at 10%, 20%, and 30%. Fig. 10 demonstrates the compressive strength result values that have been reported for all WGP replacement rates, starting at 10% and ending at 50%.

The findings of this study indicate that using of WGP as a sand supplement material in concrete mixes decreases its compressive strength. In addition, it has been proven that increasing the replacement ratio has a negative effect on the concrete's compressive strength. In other words, there is an inverse relation between the amount of WGP replacement and the concrete compressive strength. However, using low and moderate percentage rates of WGP in concrete mix showed good compressive results that are compatible with Iraqi standards.

The mix design used in this study was 1:1.5:3 which is classified C30 grade based on Iraqi technical standards for construction[22], which gives an approximate compressive strength of less than 30 MPA at 28 days for cube specimens of standard sizes 200×200×200 mm in order to be considered a successful concrete mix. However, by referring to the Fig. 10, the gained compressive strength achieved was 31 MPA at 28 days for the main control mix (MC) by using cylinder specimen. It has been proved that the compressive strength of the cylinder specimen is approximately 0.83 times the strength of the cube's specimen[23][24].

Hence, the gained compressive strength for MC was converted by multiplying its value by 1.2 to get the actual compressive strength that can be compared to the Iraqi standard; thus, the result was 37.2 MPA at 28 days after conversion. Table 5 demonstrates the compressive strength results for the age of 28 days for all replacement ratio of 10%, 20%, 30%, 40%, and 50%, the results are 33.6 MPA, 32.4 MPA, 30.6 MPA, 26.4 MPA, and 22.8 MPA, respectively. Therefore, based on the obtained results, the most optimum and feasible replacement ratio is within the range of 10% to 30%.

Table 5: Compressive strength results for all mixes at age of 28 days.

Replacement ratio	0%	10% WGP	20% WGP	30% WGP	40% WGP	50% WGP
Compressive strength for cylinder specimen [MPA] at 28 days	31	29	28	25.5	24	19
Conversion rate	1.2	1.2	1.2	1.2	1.2	1.2
Compressive strength for cubes specimen [MPA] at 28 days	37.2	34.8	33.6	30.6	28.8	22.8

5.3 Splitting Tensile strength

The result of an examination of splitting tensile strength in this study was conducted only for 30% replacement ratio which has been proven to be the optimum replacement ratio in the compressive strength test results. In addition, the test was performed by using cylinder-hardened specimens with the exact dimensions of those that have been used in compressive strength tests. In contrary to the compressive test results, the results showed that the addition of WGP increased the splitting strength as can be seen in Fig. 11. The splitting tensile strength results were recorded for the ages 7,14,21, and 28 days where the splitting tensile strength reached to 3.2, 3.5, 3.6, and 3.6 MPA, respectively, which gave about 12% improvement in tensile strength. The positive effect of glass addition in enhancing the splitting tensile strength in fact is attributed to the pozzolanic reaction mainly due to the SiO2 reactive which is considered one of the major components of cement clinker [25].

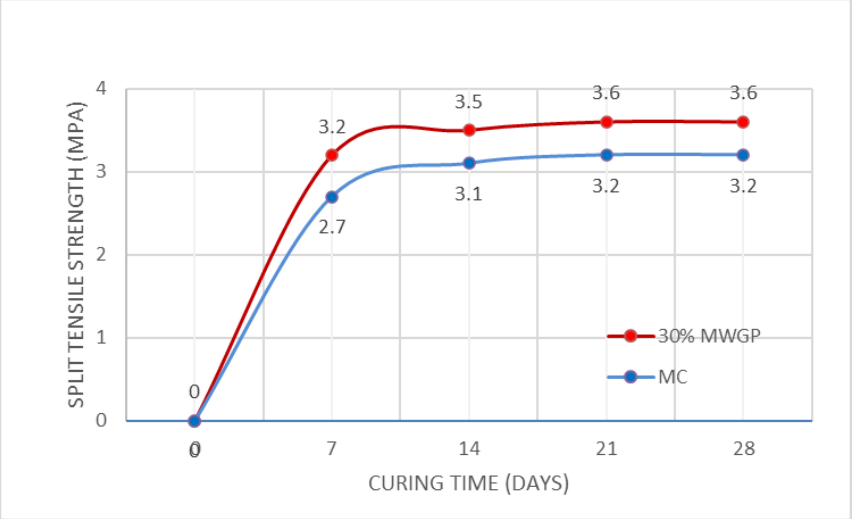


Fig. 11: Spilt tensile strength of concrete containing 30% of WGP.

5.4 FTIR, XRD, and SEM analysis results of WGP

FTIR, XRD, and SEM analysis tests were conducted for the glass powder to investigate the glass powder functional group and the main elements as well as examine the surface shape nature of the ground glass powder. From the FTIR results, it is evident that the WGP bond is O-H stretch with the alcohols-phenols functional group (see Fig. 12).

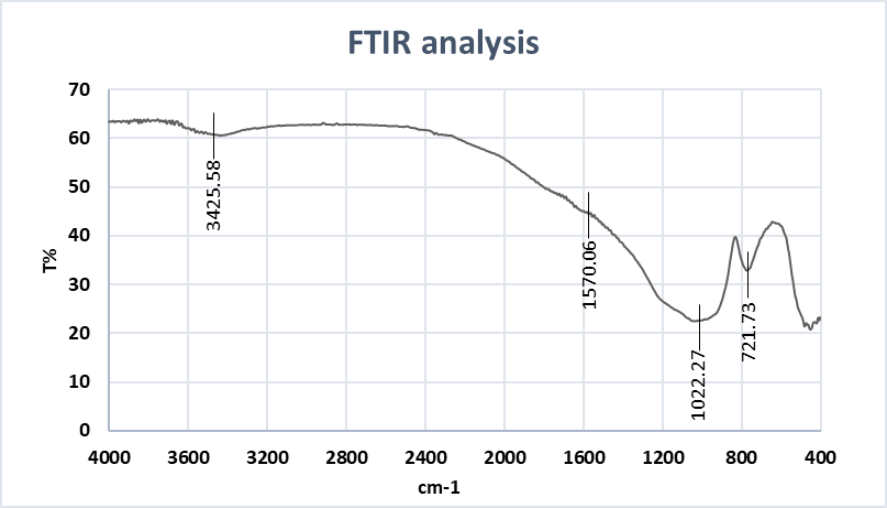


Fig. 12: FTIR analysis for waste glass powder.

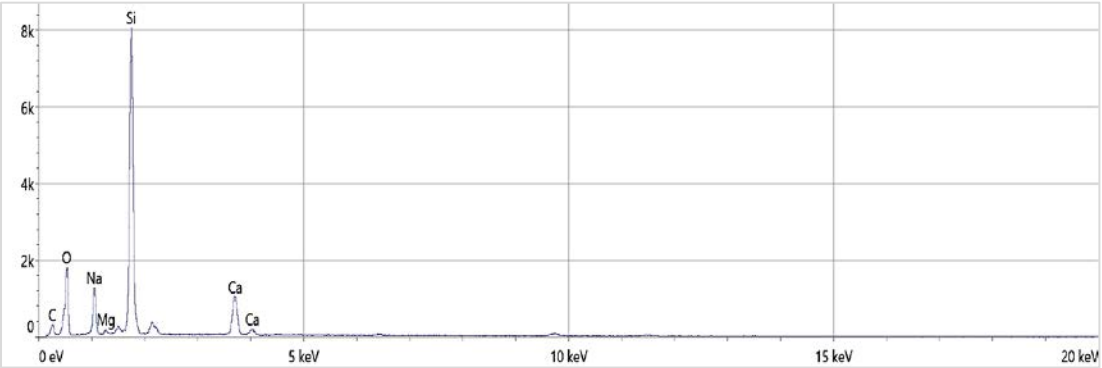


Fig. 13: XRD analysis for waste glass powder.

The XRD analysis was performed to investigate the main elements and composition that are present in the waste glass powder. Based on the observed results that are demonstrated in Fig. 13, the main observed peak element is silicon or pure silica which is also the main composition of natural sand. This observation gives great potential of replacing the natural sand with WGP in the concrete mix. Also, the presence of pure silica in WGP increases the adhesion property between cement and natural aggregate [25]. This has been proven in this study as well when the addition of WGP improved the splitting tensile strength.

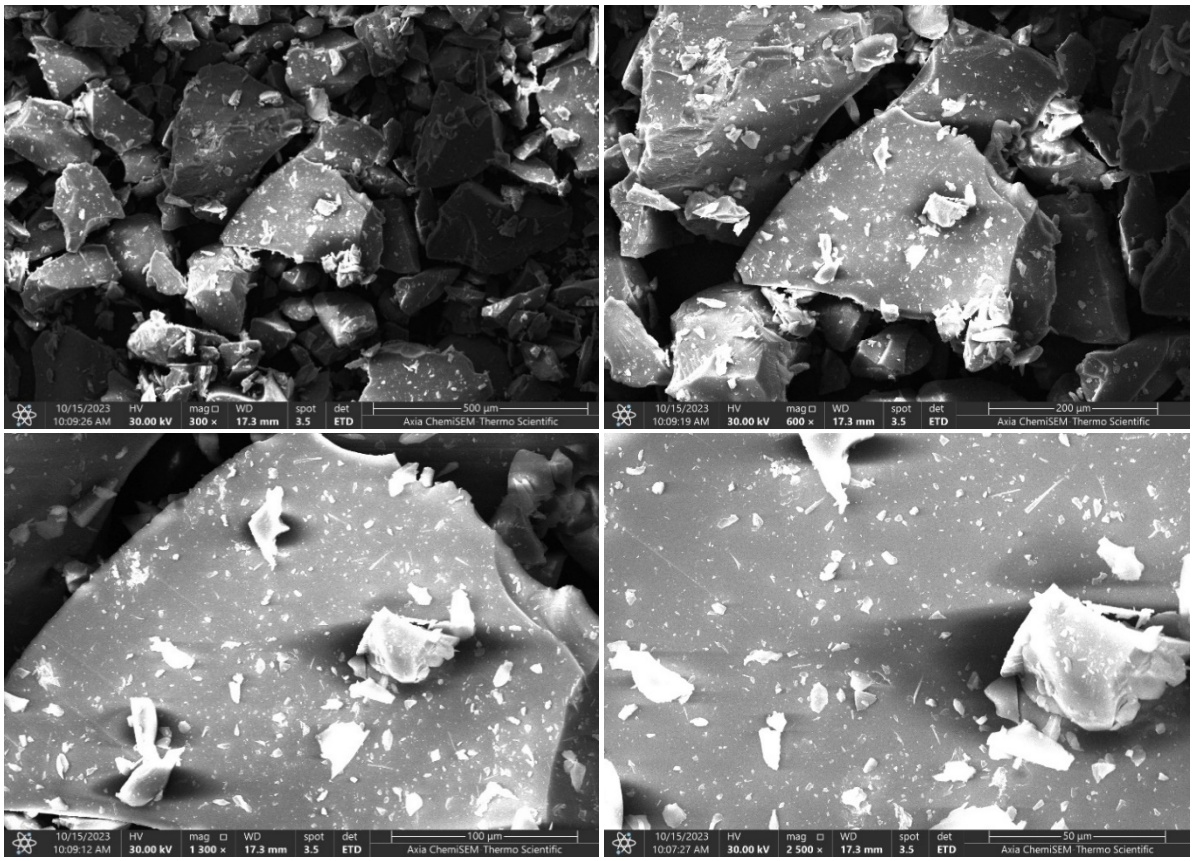


Fig. 14: SEM photomicrographs for waste glass powder.

The SEM images of the waste glass powder show that the size of the glass powder particles are within the range of 0.1mm to 0.5 mm with sharp edges (see Fig. 14). These sharp edges increased the roughness area of the mixed aggregate (natural sand mixed with waste glass powder) which has contributed to enhancing the bond mechanism between cement and aggregate.

6 Conclusion

In this research, the utilization of waste glass powder (WGP) in concrete mix design as a partial replacement with sand was studied and tested. The following conclusion points were observed from the experiment results:

• A Clear decrease in workability was observed due to WGP addition, thus more water was needed to adjust the workability and make it relatively stable for all concrete mixes design. The reduction in workability was reflected in slump test results that have been decreased from 105 mm for MC to 41mm for 50% WGP mix.

• A notable decrease in compressive strength was observed particularly with using high WGP substitution rates of up to 40% and 50% at the early age of concrete curing. The reduction in compressive strength with using 10%, 20%, 30%, 40% and 50% WGP for the age of 7 days was reported 13%, 25%, 40%, 50% and 65%, respectively.

• A significant recovery in compressive strength loss was observed after the age of 28 days when 10% to 30% of the WGP replacement ratio was used. However, when 40% and 50% of WGP addition were used, the deterioration in compressive strength continued to occur.

• From the obtained results of the concrete tests in this study, it has been proven that using WGP as a sand supplementary material is applicable in the concrete mix with a substitution rate of up to 30%, and this can be an environmental solution to utilize and reuse the glass waste and hence save the environment from a tremendous amount of glass being dump into landfill.

• The splitting tensile strength has been improved by about 12% due to WGP addition when 30% of replacement was used.

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