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Impact Resistance and Flexural Strength of Concrete Containing Fly Ash and Glass Powder

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ABSTRACT

The use of alternative materials in concrete creation has increased recently because of the mixture's advantages, both economically and technically. Incorporating some industrial waste in the concrete sector produce initiative that are sustainable in addition to developing concrete. This study focuses on the compressive, flexural, impact behavior, and attained sustainability of concrete that has glass powder (GP) and fly ash (FA) in place of some cement. Ordinary Portland Cement was used with partially replaced by FA and GP in the range of 0.0-10.10% (FA, GP), which represented by five concrete mixes. Concrete samples were subjected to testing for impact resistance, flexural strength, and compressive strength. The findings shown that while activated FA and GP reduce strengths at earlier ages (7 and 14 days), they improve compressive flexural strengths after 28 days of age. According to strength, the activated FA and GP performed best at 10% and 0% substitutes, respectively, at age 28 days. At 90 days, the best mixture performed best with ratios 10% and 10% FA and GP, respectively, also acquired maximum impact resistance. In term of sustainability, the findings demonstrated that substituting up to 20% of these wastes for cement in concrete led to a reduction in CO_2 emission of up to 25% when compared to references combination.

1. INTRODUCTION

In the field of construction, concrete is the most adaptable material. Cement, aggregates, and water are the constituents of composite material, or concrete. Significant environmental harm is caused by carbon dioxide gas emissions during the cement producing process. Worldwide emissions from cement industry are thought to provide 7% of carbon dioxide gas to the environment [1]. The development of affordable, environmentally friendly, and sustainable building materials may advance significantly with the use of different additive combinations in place of some cement [2, 3].

Pozzolanic material has been identified as a key means of reducing emissions from the making of ordinary Portland cement (OPC) since it less OPC for given purpose [4]. When pozzolan and calcium hydroxide, which are produced during OPC hydration, come together, a cementitious material is produced. By using this method, less OPC is needed to achieve the appropriate strength.

The most popular pozzolan in concrete is FA [4]. In 2016, the manufacture of concrete utilized more than 14 million tons of FA [5]. It is widely acknowledged, although, that FA is not cost-effective in many regions of nation because of the distance from FA sources, such as coal-fired power plants [4, 6]. Recent coal-fired plant closures (mostly as a result of natural gas competition) and lower FA quality as a result of pollution control measures at coal-fired facilities have made this issue worse [7]. Eighty percent of state and federal transportation agencies reported having trouble obtaining FA supplies for pavement concrete in a 2016 survey [8]. OPC usage has increased as a result of some OPC users ceasing to use FA [8, 9]. Several of states are currently looking for alternatives to pozzolan for FA. As concrete users work to manufacture more sustainable concrete materials, shortage of FA and quality issues are predicted to worsen in the future [8]. In many applications, recycled glass is either equal to or better than FA when ground to a size less than 50 micrometer, as it is a well-known effective pozzolan for concrete [10]. Due to weak local markets, less than one-third of glass containers in US are recycled [11], and an increasing number of localities are removing glass from single-stream recycling programs [12]. Eighty two percent that respond to a recent poll conducted in American communities stated that their local recycled glass marketplace was problematic [13]. This is due to fact that many materials recovery facilities (MRFs) experience glass recycling costs that are higher than their revenue due to contamination, mixed colors, and transportation expenses [12]. Roughly 25% of recycled glass is in fragments too small to be salvaged for making new glass, thus is usually dumped in landfills [13]. In the US, more than 11 million tons of glass were produced in 2017, according to the USEPA report. 4.2% of all municipal solid waste (MSW) is made up of waste glass. More than 3 million tons (more than 26%) of total amount of glass produced, were recycled in 2017. In same time more than 6 million tons were received by landfills. The amount of waste glass that can be used to meet the demand for FA replacements in concrete is considerable, especially when compared to the 14 million tons of FA used in concrete annually. FA costs approximately $40 per ton on average [14]. Substitution for FA offers a large potential economic gain as opposed to the zero negative value of recycled glass that many MRFs now face [15]. For these and other reasons, there has become an urgent need to find alternatives through which the use of FA can be reduced in exchange for the use of glass waste to rid the environment of its harms.

Several research have suggested using waste glass and FA for cement and fine aggregates, respectively. The significance of FA for enhancing the mechanical qualities of concrete is amply demonstrated by the research. The goal was to determine the cost-effective mix design for concrete that would replace cement and fine aggregate, respectively. According to the studies, the best cost-effective combination was found when 10% FA and 20% waste glass were substituted for cement and fine aggregate, respectively. To further understand the behavior of concrete containing FA, rice husk, waste glass, and steel fiber in a single research study, more research is required [16-19].

According to an experimental investigation and an examination of test findings by Kumaresan and Ayyapan [20], silica of waste glass provides concrete a very high compressive strength at early stage-28 days. It also contributes to improve the concrete toughness and longevity. It is extremely impervious to chemical assault. Every day that FA is partially add, the compressive strength grows higher. It also assists in lowering the heat produced during hydration. ASR in concrete is prevented by FA. The cost of building can be significantly decreased by replacing some of FA and GP.

Arowojolu et al. [21] replaced cement in the concrete mixture with FA and nano-GP at a weight ratio of 1% for each, and the results showed a clear improvement in the mechanical properties of the concrete produced. The results also showed that increasing the mentioned percentage leads to a negative effect on these properties. On the other hand, higher strengths in term of compressive and flexural were obtained when 10% for each of FA and GP (less than 600 µm) replaced cement in concrete [22].

Verma and Varshney [23] studied the replacement of cement in concrete by FA and GP (0%, 5%, 10%, 15%, 20% of each them). The findings indicated to increase of workability of concrete as FA and GP increased. The optimum strengths in term of compressive and flexural of concrete were obtained by the mix containing 5% of each FA and GP as replacement cement. Ramesh et al. [24] concluded that employed 30% of FA replaced cement increased the impact strength of concrete by ratio 98% at least age. Zhang et al. [25] studied the effect of adding nano-silica to concrete with ratio up to 2%. The finding indicated enhancing in impact resistance of concrete in compared with the concrete without nano-silica.

The approach of utilizing waste materials such as FA and GP is favorable to the customers, often creating concrete with cheaper cost, lesser ecological footprint, higher permanent capacity, and superior endurance over time thereby, attaining sustainability.

This study addresses an important property that has not been previously studied by any researcher for this type of concrete. Impact testing, in addition to compression and flexural, of concrete containing FA and GP is considered an introduction to the possibility of using it as structural members in construction work. The study included the use of five mixtures in which cement was replaced by 0% FA and 0% GP control mix, 5% FA and 5% GP, 10% FA and 0% GP, 10% FA and 5% GP, and the last mix with 10% FA and 10% GP. Compressive, flexural, and impact tests were conducted.

2. MATERIAL EMPLOYED

2.1 Cement

In this investigation, OPC was used, with its physical and chemical properties stated in Tables 1 and 2, respectively.

Table 1. Cement's physical characteristics

Physical Properties	Test Findings	Limits of Iraqi Specification No.5/1984 [26]
Setting time(minutes)		
-Initial setting	120	45 minutes
-Final setting	360	≤ 600 minutes
Fineness by Blaine method (m^2/Kg)	300	≥ 230
% Auto Clave	0.31	≤ 0.8

Table 2. Cement's chemical characteristics

Oxide	Weight (%)	Limits of Iraqi Specification No.5/1984 [26]
CaO	62.3	-
Sio_2	20.28	-
Al_2o_3	5.55	-
Fe_2O_3	4.20	-
MgO	2.60	5.0
K_2O	0.75	-
SO_3	0.4	-
Loss on Ignition	2.4	< 2.8
Lime saturation factor	1.65	< 0.4
Insoluble Remains	0.81	0.66-1.02

2.2 Coarse aggregate

The coarse aggregate was crushed gravel from the Al-Nabai region of Iraq, with a maximum size of 10 mm and specific gravity 2.74. Table 3 lists the coarse aggregate's sieve analysis.

Table 3. Coarse aggregate grading

Sieve Size (mm)	Acumulative Passing (%)	Iraqi Spec. Limits No.5/1984
12.5	100	100
9.5	97	85-100
4.75	15.5	10-30
2.36	6	0-10
1.18	0	0-5

Table 4. Fine aggregate physical & chemical properties

Property	Results
Specific gravity	2.6
Dry loose unit weight (kg/m^3)	1630
Sulphate content (SO_3) %	0.097
Fine materials passing 75µm sieve	2.5
Absorption %	2.3

2.3 Fine aggregate

The experiment utilized natural sand fine particles with an ideal size of 4.75 mm. Table 4 displays the physical characteristics and sulfate contents in accordance with Iraqi Standard IQ 45-1984 [26].

2.4 Fly ash

The byproduct of burning pulverized coal in electric power plants is FA a secondary fine powder. In order minimize cement for reasons of sustainability, FA of a specific gravity of 2.1 and a fineness of 380 m^2/kg was employed as a secondary binder in the current investigation. According to Table 5 listing of the chemical composition supplied by the provider, it met ASTM requirements [27].

Table 5. Components of FA

Component	Content
SiO_2	68.1
Al_2O_3	0.9
Fe_2O_3	0.6
TiO_2	14.5
Cao	1.8
MgO	2.01
Na_2O	12.2
K_2O	0.8
SO_3	0.4
P_2O_5	0.00
LIO	1.69

2.5 Glass powder

The GP used in this study was extracted by collecting a quantity of glass waste from Ramadi glass factory, and after cleaning it, it was ground finely by a mill containing steel balls so that the resultant passed through a 75-micron sieve with specific gravity 2.15. Table 6 shows the components of the glass used and is within Iraqi Specification No.45/1989 [28].

Table 6. Chemical components of glass

Component	Actual Content	Standard Limitation Iraqi 45/1989 [28]
SiO_2	72.28	72.10±0.2
Al_2O_3	1.44	< 1.45
Fe_2O_3	0.094	< 0.15
CaO	6.12	6.06±0.2
MgO	4.45	4.6±0.2
Na_2O_3	15.31	15.2±0.15
SO_3	0.24	0.3±0.1

3. MIX PROPORTIONS

Five mixtures were given names based on the amount of FA and GP they contained. The concrete mixture is denoted by the letter M, and the two appended letters with its number, F and G, represent FA and GP that were used in place of cement, respectively. The appended numbers indicated to replacement percentage of cement by these materials (FA and GP). The weight calculations for the mixtures were done as listed in Table 7. These ratios were computed utilizing data regarding these two materials that were obtained from previous studies because this study is undergoing structural loading.

It is significant to remember that by utilizing these replacement ratios now, larger ratio may be used in the future.

Table 7. Description of mixtures

Item	Cement	Sand	Gravel	FA	GP	Water
M_{F0G0}	300	750	1150	0	0	145
M_{F5G5}	270	750	1150	15	15	145
M_{F10G0}	270	750	1150	30	0	145
M_{F10G5}	255	750	1150	30	15	145
M_{F10G10}	240	750	1150	30	30	145

4. CONCRETE MIXING AND PLACEMENT

A basin mixer with a (0.1) m^3 capacity was used in a laboratory to carry out the mixing procedure. The coarse aggregate was added first, followed by the fine aggregate and cement, in order to complete the mixing process. After that, the remaining quantity of cement was applied, along with the remaining quantity of coarse and fine aggregate. After thoroughly homogenizing the mixture through dry mixing, the mixture is combined with water and mixed further in the basin mixer until a homogenous mixture is achieved. Following that, the concrete is poured into the prepared molds in three stages, and each layer is compressed for a certain amount of time using an electric vibrator. A maximum of ten seconds. Following the completion of the casting and stacking of the three layers, a trowel was used to smooth out the models' surfaces.

5. TESTING PROCESS

Casting no less than of three cubes (150 × 150 × 150 mm) determines the compressive strength of every batch mix. Three beams, each sized 100 × 100 × 500 mm, were cast to each mix in order to measure the flexural strength. Using the drop weight method of impact testing, which is advised by ACI committee 544 [29] procedures. The size of the specimen that the ACI committee recommends is 152 mm in diameter and 63.5 mm in thickness. The hammer weighs 4.54 kg and has a 457 mm drop. After casting the models, the molds were opened after 24 hours. Following all the samples had been placed in a water basin for curing, three sample were taken out for each test at the ages of 7, 14, 28, and 90 days.

6. OUTCOMES AND ARGUMENTATION

6.1 Compressive strength

Figures 1 and 2 display the test results. It is demonstrated that there were no any challenges with the compressive strength development over time for mixes comprising FA and GP. The mixtures M_{F5G5}, MF_{10G0} exhibited more compressive strength than the control mixture, but the mixtures M_{F10G5} and M_{F10G10} shown a lower compressive strength than the control mixture at 28 days. At ninety days, the mix M_{F10G10} exhibited the highest compressive strength value, exceeding the reference by nearly 13%. The next greatest values were recorded by mixes M_{F5G5}, M_{F10G0}, and M_{F10G5}, which gained 5.5%, 6.3%, and 8.5%, respectively, over the identical reference mix.

In general terms, and to help explain this, these two materials (FA and GP) interact as pozzolanic materials, relying on the byproducts of the cement-water reaction in their interactions. In a clearer form, the interaction between FA and GP and $Ca(OH)_2$, which is released during the hydration of cement. The released amount of $Ca(OH)_2$ depended on the age of concrete and continous to advance ages [30]. It follows that the three combinations responded in proportions less than the mixture with a 20% replacement rate. This age of concrete produced an adequate percentage of these byproducts, which resulted in a reasonable improvement in compressive strength. After 90 days, more interaction between the pozzolanic materials and the byproducts was possible, which resulted in a discernible rise in all combinations comprising FA and GP as opposed to the normal mixture.

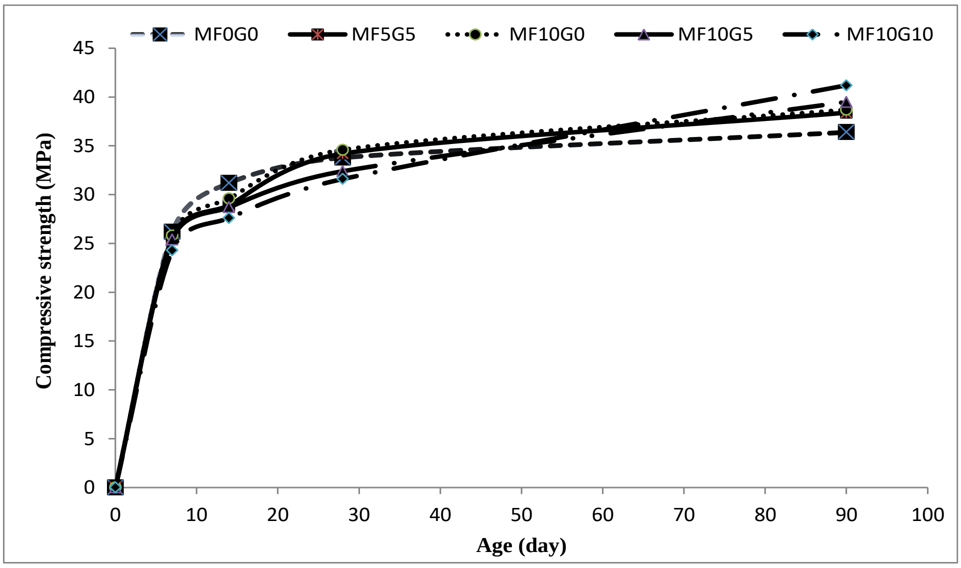

Figure 1. Strength development in term of compressive

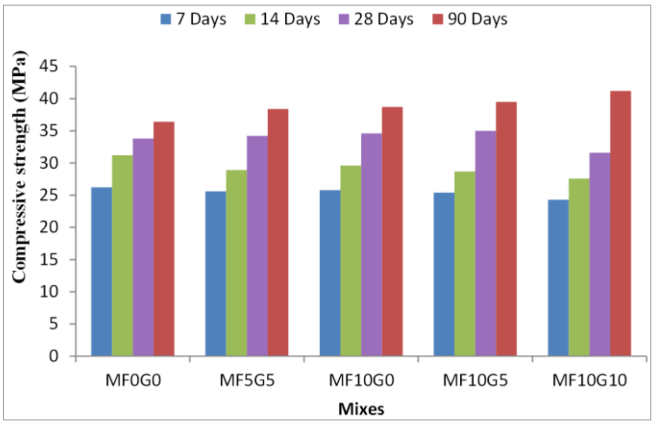

Figure 2. Compressive strength of concrete specimens at 7, 14, 28, and 90 days

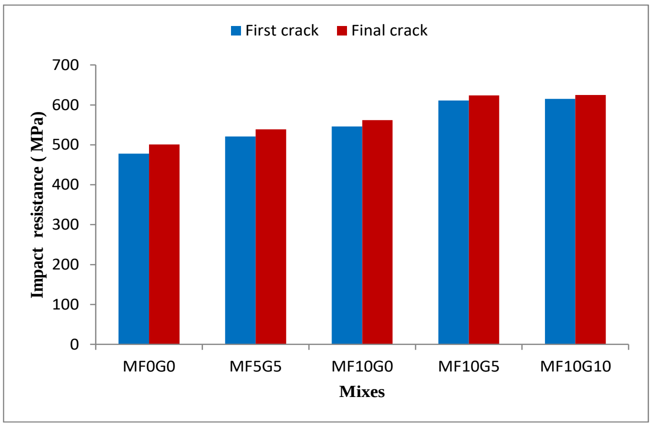

Figure 4. Impact test results of concrete specimens at 7, 14, 28, and 90 days

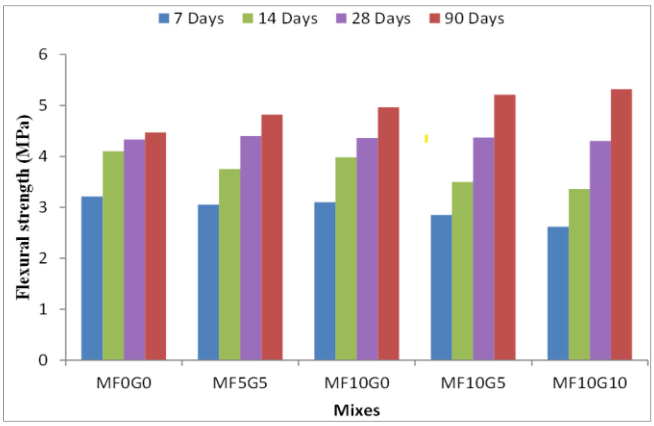

Figure 3. Flexural test results at 7, 14, 28, and 90 days

6.2 Flexural strength

The results of experiments conducted to measure flexural strength are displayed in Figure 3. The finding demonstrated that at 7 and 14 days, the flexural strength of mixtures containing FA and GP decreased. However, at 28 and 90 days, this strength quickly increased, suggesting a rise in the efficiency of pozzolanic interactions at these later stages of concrete life. It should be mentioned that the addition of GP to FA resulted in about the same strength as using FA alone to replace cement in concrete. The flexural strength gained by the combinations M_{F10G0}, M_{F10G5}, M_{F10G10}, and M_{F5G5} was less than 0.9% more than of the control mix at age 28 days, according to the data. However, these mixes increased flexural strength of around 11%, 17%, 19%, and 15%, respectively, at age of 90 days.

6.3 Impact resistance

Figure 4 displays the concrete mixtures' resistance to impact at 90 days age in term of first and final cracks. The number of blows at the start and failure of the first crack in the concrete was used to gauge its performance. The mix M_{F10G10}, which has activated 10% FA and 10% GP replacement levels, has more impact resistance than other mixes, as demonstrated by the plot (approximately 29% greater than reference mix). Impact resistance was increased by roughly 28%, 14%, and 9% in the mixes M_{F5G5}, M_{F10G0}, and M_{F10G5} compared to the control mix. It was also observed that the ratio of blows between the initial and final cracks lowers as the percentage of cement replaced by these materials rises, suggesting a boost in brittleness. The obtained findings are pointed the possibility employ this type of concrete in structural applications.

6.4 Attained sustainability

The concrete sector is un-sustainable for two several reasons. It utilizes enormous amounts of virgin materials, for the initial phase. The primary bind in concrete is OPC, whose manufacture is a significant source of greenhouse gas emissions associated with climate change and global warming. One of the study programs highlights the attainment of sustainability by mean of a decrease in CO_2 emissions across all mixes utilized, according to the estimated amount of CO_2 (866kg) released during manufacturing of one ton of cement [31]. The sustainability attained listed in Table 8. Based to the finding, the mixtures which included 10%, 15%, and 20% waste (FA and GP) in place of cement lowered the release of CO_2 by 11%, 18%, and 25%, respectively, in juxtaposition with the mix without FA and GP per cubic meter production.

Table 8. Amount of CO_2 released

Item	CO_2 Released (kg/m^3)	Reduced Ratio%
M_{F0G0}	259.8	0
M_{F5G5}	233.8	11
M_{F10G0}	233.8	11
M_{F10G5}	220.8	18
M_{F10G10}	207.8	25

7. CONCLUSIONS

From what was studied in this paper and the tests that were conducted on concrete samples containing different percentages of FA and GP in addition to the reference mixture, it is possible to conclude the following:

• It is possible to manufacture natural concrete for construction projects where time is of the essence by substituting 5% FA and 5% GP for cement in concrete mixtures and 10% FA alone replacement rate. If steps are taken to post pone imposing the maximum load on this type of concrete until after has been in place for 90 days, higher replacement rates—up to 10% FA + 10% GP—may be employed.

• At 90 days of age, the compressive strengths of all mixes in which FA and GP were substituted for cement exceed the reference. This was demonstrated by the combinations M_{F10G10}, M_{F10G5}, M_{F10G0}, M_{F5G5}, which grew in strength in comparison to the reference mix by 13%, 8.5%, 6.3%, and 5.5%, respectively. Although these mixes showed reduction in compressive strength at 7 and 14 days due to cement activity at these ages best of the materials of replacement.

• The flexural strength of mixes containing FA and GP were increased at 90 days of age, despite the fact they had noticed a reduction in this strength at early ages (7 and 14 days). Up to 28 days of age, mixtures with replacement ratio as 10% revealed some increase in flexural strength. The flexural strength of mixtures M_{F10G10}, M_{F10G5}, M_{F10G0}, and M_{F5G5} grows by 19%, 16.5%, 11%, and 7.8% at age 90 days, respectively. These mixtures' early ages revealed a decline in strength, which implies a delay in the pozzolanic materials' reaction, until 28 days in which the reaction began.

• The mixtures were gained clearly impact resistance at age of 90 days. The mixtures M_{F10G10}, M_{F10G5}, M_{F10G0}, and M_{F5G5} were resulted increasing in impact resistance by 28.6%, 27.8%, 14.2%, and 9% more than the control mix. It was noticed that with the increasing replacement ratio level the difference of blows between the first and final cracks decreased, which indicates to gain more brittleness.

• Using FA and GP to replace cement in concrete by up to 20% reduce CO_2 emissions by up to 25% compared to ordinary concrete.

• For future research, this study opens a broad horizon for studying the uses of these wastes in many construction fields due to their binding effectiveness in the presence of cement, in addition to the possibility of using them in structural fields. This requires expanding the evaluation of their uses.

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