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The performance of steel fibre reinforced concrete with waste glass as partial replacement of fine aggregate

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The performance of steel fibre reinforced concrete with waste glass as partial replacement of fine aggregate

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Abstract. This paper discusses the performance of steel fibre reinforced concrete with part of substitution of sand with waste glass in concrete mix. Glass consists mainly of silica, which is a natural raw substance like sand. Glass is completely recyclable, and it can be recycled indefinitely without losing any of its quality or purity. Waste glass powder was utilized as a partial replacement of fine aggregate with 0%, 10%, 20 and 30% by the volume in C30 grade of concrete and addition of 0.5 % steel fibre by volume fractions of hooked end steel fibre and 0.5 water cement ratio. All samples were evaluated following 28 days curing period. The aim of this study is to investigate the workability of concrete, to determine the compressive and tensile strength of concrete and to identify the optimum percentage of steel fibre reinforced and waste glass. From the experimental results, it was found that the study achieved a maximum compressive strength of 32.9 N/mm² at 30% replacement of fine aggregate with waste glass, slightly surpassing normal concrete. Additionally, the highest tensile strength of 3.9 N/mm² was achieved at 20% replacement, surpassing normal concrete. The optimum percentages determined were 20% for fine glass replacement and 0.5% for steel fiber addition. It can be concluded that scenario of waste glass concrete approach could be perceived as a sustainable and environmentally friendly product in the near future.

1. Introduction

The focus on sustainable development has turned progressively crucial in the recent years, as the rapid industrialization of both developed and developing nations has led to concerns about non-sustainability. The utilization of concrete as a basic material in the construction sector plays a crucial part in the growth of infrastructure in any region [1]. Concrete for centuries has been the most widely used material for civil construction around the world. It is preferred because of its high compression efficiency, high durability, extended life, and minimal maintenance cost [2]. Since concrete is a material utilized in many projects that improve people's standard of living, its production provides a vital source of supply for the civil construction industry. The global usage of concrete is estimated at 11 billion tonnes per year, or around 1.9 tonnes per inhabitant [3]. Increasing demands for landfill area and natural resources, as well as a focus on minimising the construction industry's carbon footprint, have made glass waste disposal is a major environmental concern [4]. The reuse of waste glass is one of the most important issues around the world due to the increase of solid wastes in the landfill and non-degradable nature of its disposal. There has been significant international interest in using recovered waste glass in concrete [5]. Glass is produced in different shapes, counting container glass, flat glass, bulb glass, and is subject to recycling due to its limited lifespan. Waste glass constituted 5 percentage of universal municipal solid waste produced in 2016, and this percentage has remained unchanged in 2022, as reported by the World Bank [6]. The recycling rate for glass varies globally and within regions, indicating a need for improved waste management and increased recycling efforts to decrease the environmental effect of waste [7].

The usage of glass waste in the concrete building industry has enormous potential. Glass is infinitely recyclable without degrading in quality or purity and can be recycled endlessly. Earlier investigations have shown that recycled glass fine can be utilised in as a sand substitution in concrete [8]. On the other hand, in plain cement concrete, structural cracks can appear even before the concrete is loaded, especially when drying shrinkage or causes of volume change. Uniformly distributed fibres can be included to the concrete in order to enhance its qualities and prevent cracking as well as to increase tensile strength. In this research steel fibre was used to increase the tensile properties of the concrete. Thus, researching the performance of concrete containing glass waste is crucial to ensure that the concrete mix design is just as strong as traditional concrete used in the construction sector. This study hence replaces part of fine aggregate as glass waste in steel fibre reinforced concrete, an attractive choice for economic and industrial sectors.

2. Materials and Methods

The primary aim of this study is to assess the performance of steel fiber reinforced concrete incorporating waste glass as a partial replacement for fine aggregate. The study focused on investigating key mechanical properties, specifically the compressive strength and tensile strength of the concrete. The study involved the utilization of specific materials for casting concrete samples, and the results of various properties tested were thoroughly evaluated. Materials used in this study consist of Portland cement was used, also fine aggregate not more than 5 mm, coarse aggregate of size of less than 20 mm was used, steel fibre and three different percentage of glass waste was also utilized as a part of substitution of sand.

2.1. Waste glass

Glass is composed primarily of SiO_2 and can therefore be substituted with sand. High temperatures are applied to a small number of basic materials, including china clay, dolomite, quartz, calcium carbonate and feldspar in order to produce glass. Subsequently melting, the molten combination is permitted to cool, where it crystallises into a transparent, crystalline material known as glass. The process to get fine waste glass was generated by researcher that to fulfil the standard EN 12620 (2002). First, the waste glasses bought from a local recycling factory, then the waste glass is cleaned to prevent microbes. The waste glass crushed into small particles size by using crush machine in the FKAAB laboratory, as it can be perceived in Figure 1, the glass fragments were first transported to a crushing mill where they were additional crushed into a fine glass. The crushed fine is then sieved to achieve an unvarying dimensions of less than 5 mm, meeting the requirements of BS EN standards in the process.

Figure 1. Fine recycled glass powder

2.2. Steel fibre

Fiber Reinforced concrete (FRC) is concrete that includes fibres to improve the material's structural strength. It is made up of short, random-oriented fibres that are scattered uniformly. The usage of fibres in concrete improves its tensile strength, flexural strength, and durability performance and it gives capacity to shift stresses over a cracked sector, which primarily indicates an increase in toughness. Hooked-end steel fibres Dramix 3D it technology used Bekaert were used in this study as displayed in Figure 2 and Table 1.

Table 1. Material characteristics of steel fibre Dramix 3D 80/60 BG

3D Dramix 80/60 BG	Value
Tensile strength	1.225 N/mm^2, Tolerances: ±7.5% Avg
Young's modulus	± 210.000 N/mm^2
Length in mm	60 millimeter
Diameter in mm	0.75 millimeter

Figure 2. Fine recycled glass powder

2.3. Mixture Proportion of Concrete

The concrete mix was designed using the British Department of Environment (DOE) procedure. The design was based on the volume of a cylinder. Calculations were made for the required amounts of water, sand, coarse aggregate, cement. Concrete grate design characteristic strength of 30 MPa after period of 28 days was considered to achieve the study aim. Water cement ratio that used in this study is 0.5. In concrete proportioning, up to 30% percentage of waste glass replaced as sand. During the mix process 0.5% percentage of steel fibre is added the mix. The design mix was executed for the controlled specimens of C30/37 grade concrete referred to as "Control Specimens" in this study. Table 2, 3 and 4 displays the mixture ratio and percentage of concrete arranged for this research.

Table 2. Mix design ratio of C30/37 concrete per 1 m^3

No.	Material	C 30/37 in kg/m^3 and litres
1	Cement	380
2	water	190
3	Fine aggregate	659
4	Coarse aggregate	1171

Table 3. Mixture proportion of concrete

No.	Mix Design	Cement	Coarse Aggregate	Fine Aggregate		Steel Fibre	W/C
				Sand	WG		
1	Controlled	100%	100%	100%	0	0	0.5
2	10%GP + 0.5 SF	100%	100%	90%	10%	0.5%	0.5
3	20% GP + 0.5% SF	100%	100%	80%	20%	0.5%	0.5
4	30% GP + 0.5% SF	100%	100%	70%	30%	0.5%	0.5

Table 4. Concrete mix design of Steel fibre and fine WG as replace of fine aggregate / 0.01071 m^3

No.	Specimens name	Waste glass (kg)	Volume of steel fibre %	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Cement (kg/m^3)	Water (kg)
1	Control	0	0	7.06	12.6	4.1	2
2	10%GP + 0.5 SF	0.70	0.5	6.36			
3	20% GP + 0.5% SF	1.41	0.5	5.65			
4	30% GP + 0.5% SF	2.12	0.5	4.94			

2.4. Sample Preparation

In this study, numerous specimens in different percentages casted in order to conduct a compressive strength and splitting tensile test. The concrete cylinder and cube samples used in both tests mentioned above. All samples undergone curing process for 7 and 28 days before tested. Hardened concrete laboratory testing, concrete cylinder and cube were prepared for each percentage of waste glass and steel fiber materials. The details on the number of specimens in this research are displayed in Table 5. All the tests are performed on a total of 36 cylinder and cube, each of which is 100 mm in diameter and 200 mm in height cylinder and cube of 100 mm by 100 mm by 100 mm. A thin film of mould oil was applied to the mould and base plate before use to avoid concrete adherence. A tamping rod or vibrator are needed to do the concrete sample as it is the main equipment for this sample to avoid honeycomb.

Table 5. Number of specimens mix design

No.	Mix Design	Compressive strength		Tensile strength
		7 days	28 days	28 days
1	Control	3	3	3
2	10%GP + 0.5 SF	3	3	3
3	20% GP + 0.5% SF	3	3	3
4	30% GP + 0.5% SF	3	3	3
Total			36	

2.5. Testing method in specimens

In this study, three evaluations were conducted to achieve the main objectives of the study. The slump test was performed for fresh concrete to examine the workability of the materials used in this study, the test is executed in following BS EN 12350-2:2009 standard, and compressive strength test was done to gain the strength of resulting features on the concrete following the standard as stated according to BS EN 12390-3:2009 and splitting tensile test was implemented to check the strength of hardened state concrete. Split tensile test was determined by using the following standard as stated in BS EN12390- 6:2009.

3. Results and discussion

3.1. Physical properties of fine aggregate and waste glass

Fine aggregate is a commonly used material in concrete, where normal dry river sand is typically employed. According to EN 12620 (2002) standards, fine aggregates are required to pass through a 5 mm sieve and be free from any impurities. In contrast, waste glass is a non-biodegradable material that often takes the form of crushed waste bottles. For this project, the waste glass was collected from restaurants, and all unwanted materials such as labels and corks were removed. The glass was then washed and crushed into the necessary sizes. The properties of fine aggregate and waste glass can be found in Table 6.

Table 6. Properties of fine aggregate

S.no	Properties	Fine aggregate	Waste glass
1	Specific gravity	2.64	2.37
2	Fineness Modulus	2.85	3.5

On other hand, gradations curves were plotted and compared with the standardized one as shown in Figure 3.

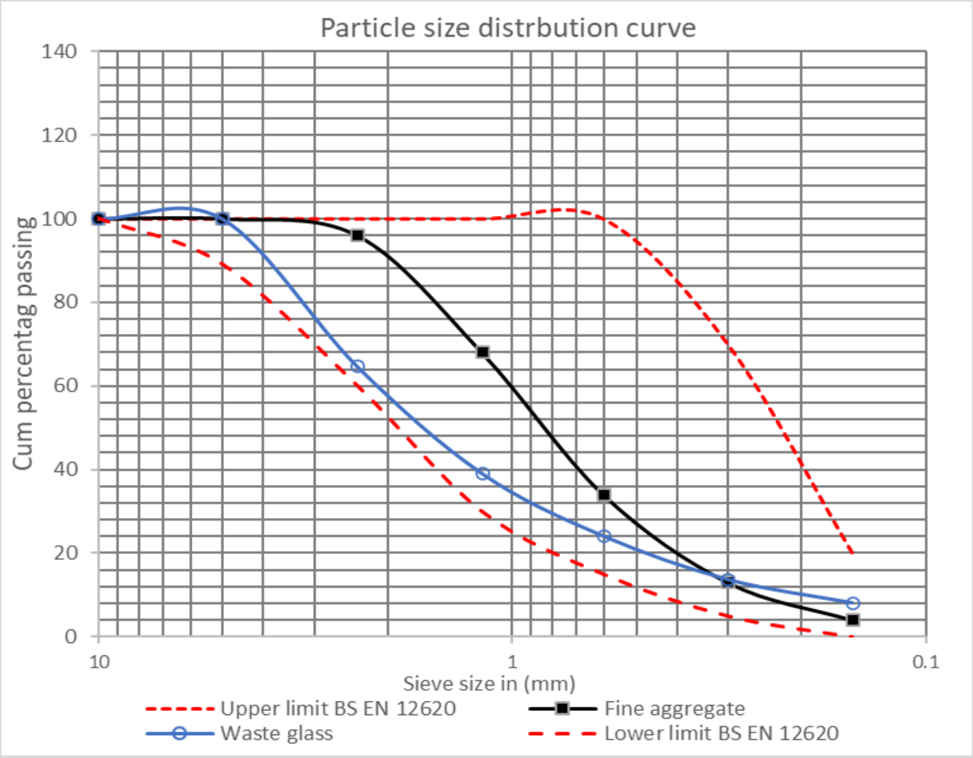

Figure 3. Fine recycled glass powder

Figure 3 displays the particle size distribution curve for riverbed sands and waste glass. Both representations illustrate that the grading curves of both materials fall within the range of two grading limits. This unexpected finding suggests that crushed waste glass particles is remarkably close to that of fine aggregate. Therefore, it can be confirmed that the particle grading of waste glass aligns with the necessary grading of fine aggregates for the production of concrete.

3.2. Workability of SF and WG

According to the graph in Figure 4, the maximum slump evaluated for regular concrete without replacement and adding steel fibre is 57 mm. The slump values for SFRC 0.5% and WG10%, which is a 10% replacement of waste glass with sand, were 52 mm. Nonetheless, the slump values remained within the standard-approved range of 30 to 60 mm. The slump of the remaining concrete mixtures from WG20 % and WG30 % is 45 mm and 41 mm, respectively. As shown in Figure 4, when the percentage of replacement was zero, the workability was the highest. However, when the percentage of replacement was 10 percent of fine aggregate with waste glass, the workability began to decrease. Therefore, we can say that steel fibre and waste glass affected the workability of the mixture, as indicated by the date, because as the amount of glass in the mixture increased, its workability declined. The data also shown that all of the sample was in the medium range and in true slump condition. All of the concrete containing SFRC and WG had lower slump readings compared to normal concrete.

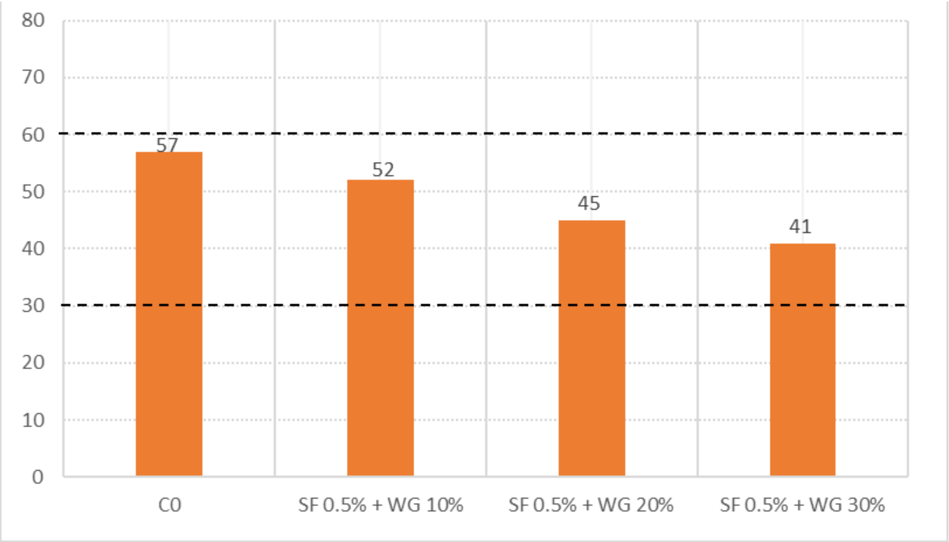

Figure 4. Workability results

3.3. Compressive strength

Table 7 and Figure 5 shows how the influence of steel fibre and waste glass might affect that compressive strength of concrete after 7 days of curing. It is clear that all of the mixtures achieved and exceeded the strength of 70 % of necessary strength after a curing period of 7 days. The compressive strength of the control concrete on day 7 was a result of 23.7 N/mm^2, according to the findings of the study. In addition, the compressive strength decreased after 10% replacement for 9.8% compared to the control concrete, also 20% replacement decreased for 11% compared to the control concrete and 30% replacement of fine aggregate was 1.3% which almost same strength value as control concrete. All of the concrete containing SFRC and WG had a lower compressive strength reading compared to normal concrete after 7 days of curing.

Table 7. Compressive strength of SFRC and WG for 7 and 28 days

S.no	Concrete mix	Waste glass %	Steel fibre %	Compressive strength 7 Days (N/mm^2)	Compressive strength 28 Days (N/mm^2)
1	C0	0	0	23.7	32
2	WG1	10%	0.5%	21.4	30
3	WG2	20%	0.5%	21.1	31.1
4	WG3	30%	0.5%	23.4	32.9

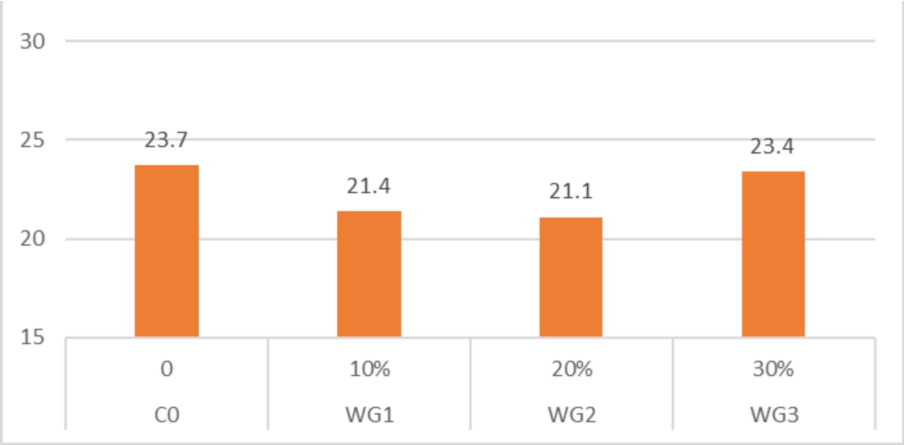

Figure 5. Compressive strength of SFRC and WG development for 7 days.

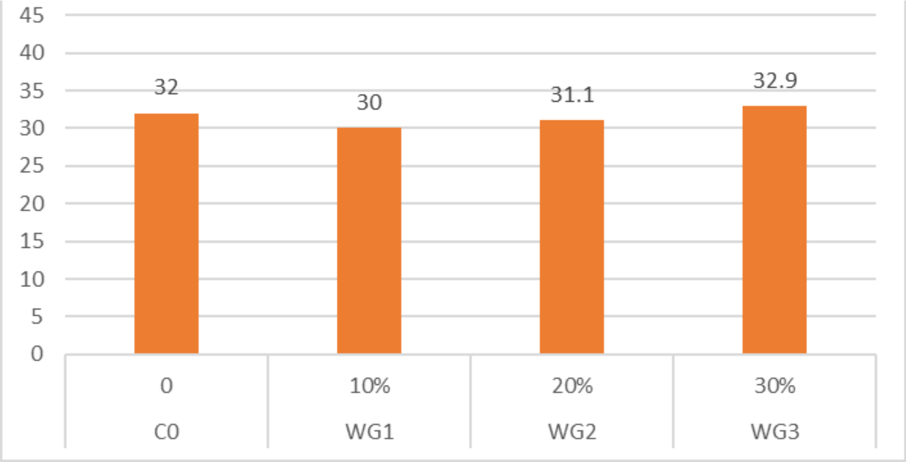

Figure 6. Compressive strength of SFRC and WG development for 28 days.

The compressive strength of the control specimen for 28 days of curing result obtained was 32 N/mm^2 as shown in Figure 6. In addition, the compressive strength decreased after 10% replacement for 6.3% compared to the control specimen, also 20% replacement decreased for 2.8% compared to the control specimen. The highest compressive strength value of 32.9 N/mm^2 was achieved after a curing period of 28 days using a 30% mixture of waste glass and 0.5% steel fibers, resulting in a 3.8% increase over the control specimen. Conversely, the lowest compressive strength value of 30 N/mm2 was obtained in a mix with 10% WG replacement and 0.5% SF addition, showing a 6.3% decrease compared to the control specimen, as illustrated in the graph below. Therefore, it is clear that all mix proportion achieved the design mix of C30 grade of concrete.

3.4. Split tensile strength

Based on split tensile strength result presented in Table 8 and Figure 7, following a curing period of 28 days it shows that control samples recorded the lowest tensile strength of 2.9 N/mm^2 at 28 days. Data presented in Figure 7 graph shows versus mix proportion results. The splitting tensile strength result increased with the increase percentage of replacement in concrete mix till 20% replacement, then splitting tensile strength decreased at 30% of replacement which is 3.4 N/mm^2 at 28 days of curing compared to 20% of replacement. The highest tensile strength in concrete is achieved with 0.5 % inclusion of steel fibre and 20% replacement of waste glass exhibited the maximum strength of 3.9 N/mm^2. This represented a substantial increase of 34.5% over the control specimen. However, it's noteworthy that the strength gradually declined with higher levels of waste glass substitution and steel fiber inclusion. These findings suggest that the split tensile strength saw significant improvement with the inclusion of 0.5% steel fiber by volume, but it decreased as the level of waste glass substitution exceeded 20% after the 28-day curing period.

Table 8. Split tensile strength of SFRC and WG for 28 days.

S.no	Concrete mix	Waste glass (%)	Steel fibre (%)	Split tensile strength 28 Days (N/mm^2)	Percentage of increment
1	C0	0	0	2.9	--
2	WG1	10	0.5	3.1	6.9%
3	WG2	20	0.5	3.9	34.5%
4	WG3	30	0.5	3.4	17.2%

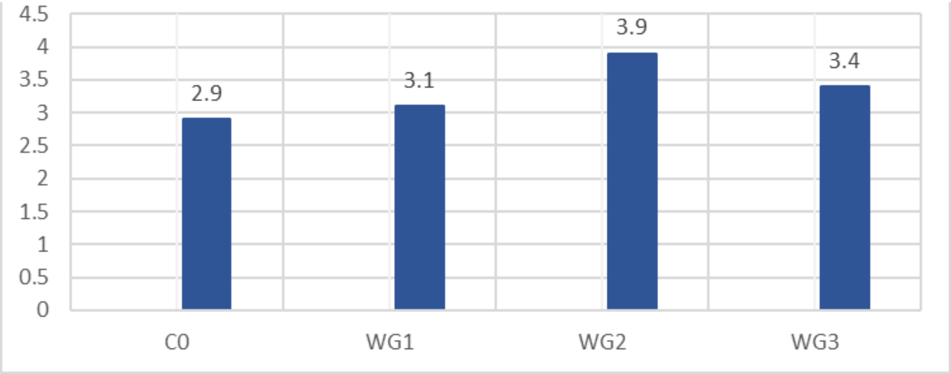

Figure 7. Split tensile strength of SFRC and WG development for 28 days.

3.5. The optimum combination percentage of steel fibre and waste glass

The optimum combination percentage of steel fiber and waste glass can vary depending on the specific application and desired properties of the concrete. The key parameters this study focused on are the slump test, split tensile strength, and compressive strength. The slump values decrease as the percentage of waste glass increases, indicating a decrease in workability. However, the difference in slump values between 20% and 30% replacement is relatively small. Therefore, it can be inferred that the optimum percentage lies between 20% and 30% as it maintains an acceptable workability level while utilizing a higher percentage of waste glass. The split tensile strength generally increases with the addition of waste glass up to 20% replacement. However, at 30% replacement, the split tensile strength slightly decreases. This suggests that the optimum percentage could be around 20% as it provides the highest split tensile strength. The compressive strength values remain relatively consistent across the different percentages of waste glass. There is no significant improvement or decline in compressive strength with the addition of waste glass. Overall, considering all the test results it can be said that for C30 grade of concrete mix, 20% replacement of fine aggregate by waste glass and inclusion of 0.5 % steel fiber is considered as optimum percentage.

4. Conclusion

- The results for workability show that increasing replacement percentage of waste glass and addition of steel fibre decreased the workability of concrete. Most of the mixes measured where true slumps.
- The compressive strength of the steel fiber reinforced concrete with partial replacement of fine aggregate with waste glass did not show a significant increase or impact. The tensile strength of this study shows much improvement compared to normal concrete, the highest tensile strength achieved was 3.9 N/mm² at 20% replacement which is greater than normal concrete at 34.5%.
- The study identified that the optimum percentage of fine glass is 20%, while the optimum percentage of steel fiber is 0.5%.

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