Engineering Research Journal

journal homepage: https://erj.journals.ekb.eg/

Producing Environmentally Sustainable and Wear- Resistant Rigid Pavement Utilizing Glass Powder

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Abstract. Recent trends have seen an increased use of industrial by-products, such as blast furnace slag, fly ash, and glass powder, to enhance the mechanical properties of concrete, particularly in applications requiring high abrasion resistance, such as rigid pavements. This paper examines the performance of concrete where glass powder is utilized as a partial replacement for sand. The sand was substituted with glass powder in varying proportions, ranging from 0% to 20% of the cement weight. To enhance the abrasion resistance and durability of concrete, glass powder is being utilized, which also contributes to improved compressive and flexural strengths, ultimately extending the lifespan of rigid pavement structures. Tests conducted included air content, slump, flexural strength, compressive strength, abrasion resistance, absorption, X-Ray Diffraction (XRD**)**, X-Ray fluorescence (XRF) and Scanning electron microscope (SEM). The results show that the optimal strength of concrete is achieved at approximately 15% glass powder when using cement Elarish and around 10% glass powder when using cement Elsewedy.

Keywords: Concrete, Glass powder, Strength, Rigid pavement.

1. INTRODUCTION

In Egypt, the rapid development of infrastructure and road systems requires significant upgrades. To accommodate the increasing traffic loads, Rigid pavement (concrete) has been adpoted as an alternative to flexible asphalt pavement to accommodate the increase in traffic load.. Utilization of rigid pavement is necessary as high traffic loads are the primary cause of numerous issues in asphalt pavement, such as rutting, fatigue, slippage cracking, corrugations, and shoving. Glass powder has been utilized in rigid pavement as it enhances the abrasion resistance and durability of concrete. As well, glass powder contributes to improve compressive and flexural strengths, ultimately extending the lifespan of rigid pavement structures.

DOI: 10.21608/erj.2025.367467.1221
Received 19 March 2025; Received in revised form 19 March 2025; Accepted 10 April 2025
Available online 01 June 2025

2. LITERATURE REVIEW

The use of waste glass powder (WGP) in concrete is gaining significant attention, especially in rigid pavement, due to its potential to enhance the sustainability of construction practices and the mechanical properties of concrete. As a partial replacement for traditional materials like cement and fine aggregates, WGP helps address environmental concerns associated with waste disposal and resource depletion. The incorporation of glass powder in concrete contributes to sustainable development by recycling glass waste, reducing the carbon footprint of cement production, and conserving natural resources used in concrete production Muhedin & Ibrahim, (2023).

In terms of mechanical properties, concrete containing WGP has demonstrated improvements in both compressive and tensile strength. Studies show that replacing a portion of cement or fine aggregate with glass powder can increase the compressive strength of concrete by up to 20%, enhancing its overall durability and load-bearing capacity Arivalagan & Sethuraman, (2021). The tensile strength also sees notable improvements, making the concrete more resistant to cracking and deformation under stress. These enhancements make WGP a viable option for sustainable and high-performance concrete applications.

Several studies have focused on the use of waste glass powder (WGP) as a partial replacement for cement and sand in concrete. For instance, Muhedin & Ibrahim, (2023) examined the effects of 5%, 10%, and 15% WGP replacement and found that it enhances concrete strength, while higher percentages reduce it. Their study also highlights how WGP improves the concrete microstructure by boosting pozzolanic activity and reducing microcracks. Similarly, Al-jburi Najad et al.,(2019) explored unconventional applications of waste glass in cement and concrete, emphasizing its thermal and pozzolanic activities and their influence on the material's properties. This research further investigates how the characteristics of waste glass affect durability and performance.

In a separate study, Ali et al., (2017) investigated the effectiveness of WGP in improving the mechanical properties of concrete at high temperatures. Their findings show that the chemical composition of WGP enhances concrete strength and helps maintain residual strength at elevated temperatures. They concluded that high-strength concrete (HSC) made with WGP performs better than concrete made with silica fume at high temperatures. Du & Tan, (2014) examined the pozzolanic reactivity of WGP at different cement replacement levels and concluded that using glass powder as a 15% additive significantly improves the strength and impermeability of high-performance concrete.

Furthermore, Hamada et al., (2022) reviewed the mechanical and durability properties of concrete containing waste glass aggregates (WGA). They found that the size, type, replacement ratio, and mixing methods greatly influence the concrete's characteristics, with powdered glass enhancing durability through a refined pore structure. Their recommendations for further research focus on the potential use of waste glass as both coarse and fine aggregates. Similarly, Kumar & Nagar, (2017) studied WGP as a partial replacement for fine aggregates to determine optimal compressive strength.

Research by Olofinnade et al., (2017); Dhirendra et al., (2012) evaluated concrete with ground waste glass powder as a partial cement replacement, showing that this method offers an efficient waste management solution without negatively impacting concrete performance. Khatib et al.,(2012) also analyzed the performance of concrete with 0% to 40% glass powder replacing Portland cement, finding that a 10% replacement achieved the highest compressive strength. In addition, Jangid & Saoji, (2014) tested varying percentages of glass powder replacement and concluded that finely ground waste glass, with its high SiO2 content, exhibits pozzolanic properties that aid strength development.

Further studies, such as Vikas Srivastava, (2015), investigated crushed waste sheet glass as a replacement for cement and fine aggregate. The results showed higher compressive strength in concrete made with waste glass compared to conventional concrete at all replacement levels. Malik et al., (2013) focused on the use of waste glass as a replacement for fine aggregates and concluded that up to 30% replacement by weight yields positive results in compressive strength, tensile strength, and durability. Nwaubani & Poutos,(2013) added that although early-age compressive strength decreases with increased glass powder content, later-stage strength improves due to the pozzolanic reaction. Lastly, Vandhiyan et al., (2013) explored recycled glass powder as a partial replacement for cement in concrete, showing improvements in mechanical properties and highlighting its economic benefits.

Other studies focused on the harmful alkali-silica reactions, such as Du & Tan (2013), which examined the use of waste glass in concrete, provided that the potential deleterious expansion caused by alkali-silica reaction (ASR) could be mitigated. Idir et al., (2009) suggests that reusing glass in concrete can offer a sustainable solution for glass storage. Depending on the particle size, two opposing behaviors can occur a harmful alkali-silica reaction or a beneficial pozzolanic reaction that enhances concrete properties. The study focused on using fine glass particles and aggregates in mortars, finding that glass grains smaller than 1 mm do not cause swelling due to the alkali-silica reaction, while fine glass powders with specific surface areas between 180 and 540 m^2/kg help reduce expansions in mortars when larger glass aggregates are used.

The workability of fresh concrete, along with its compressive and flexural strength, in addition to its abrasion resistance, are among the most important properties of concrete in general and rigid pavement's concrete in particular. Many researchers have sought to improve these properties by adding different materials to improve one or more of the previously mentioned properties. Several studies have examined alternative materials as partial replacements or additives to improve concrete performance. Adewuyi et al. (2017) enhanced compressive strength and abrasion resistance using crushed granite, which improved interlocking within the concrete matrix. Bahedh and Jaafar (2018) demonstrated that fly ash increased the compressive strength and workability of ultra-high-performance concrete (UHPC) through pozzolanic reactions. Additionally, Teerasak Yaowarat et al. (2021) found that natural rubber latex (NRL) improved flexural strength, making concrete more resistant to cracking and deformation.

3. RESEARCH OBJECTIVES

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The objectives of this study are summarized as follows: -

1. Improving the wear resistance properties of rigid pavement.
2. Obtaining concrete with high resistance to compression and flexural.
3. Obtaining a high workable concrete.
4. Increasing the life span of rigid pavement.

4. MATERIAL

4.1 Sand

Sand sourced from Abu Ajwa quarry in AL-Saf, Egypt was used in this study. Various experiments and tests were conducted to determine the physical properties of the sand. Gradation tests were performed to analyze the distribution of sand sizes and presented in chart 1 . along with the physical properties of the sand , were compiled and presented in Table 1.

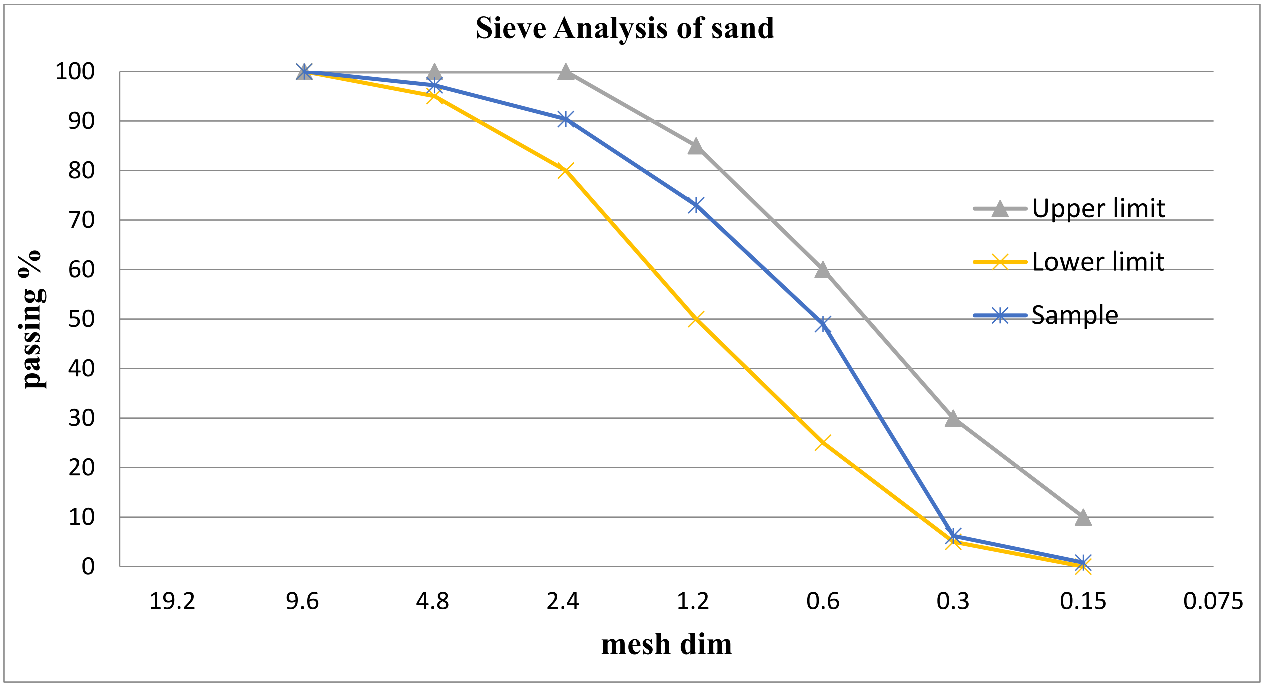

Fig.1. Sieve Analysis of sand

Table 1 . Physical Characteristics of sand

NO	Tested Propertiy	Test specification	Limits	Measured
1	SSD (Specific Weight) t/m^3	Test 2-4**	2.5-2.75	2.68
2	moisture content %	Test 2-3**	-----	0.09
3	Absorption Ratio %	Test 2-3**	Max 2.0%	0.67
4	Bulk Density. t/m^3 compacted un compacted	Test 2-5**	-----	1.703 1.617
5	Clay Lumps and Friable Particles	Test 2-11**	Max 3.0%	0.17%
6	Organic Impurities	Test 2-21**	Nil	Nil
7	Chloride Content (CI)	Wet Chemical Analysis	Max 0.06%	0.04%
8	Sulfate Content (SO_3)		Max 0.40%	0.226%

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4.2 Aggregate

Crushed aggregate sourced from Atta 'a mountain in Suez, Egypt was used in this study. Various experiments and tests were conducted to determine the physical properties of the aggregate. Gradation tests were performed to analyze the distribution of aggregate sizes and presented in figure 2&3&4. The results of these tests, along with the physical properties of the aggregate, were compiled and presented in Tables 2, 3 and 4.

4.2.1 Aggregate (size I)

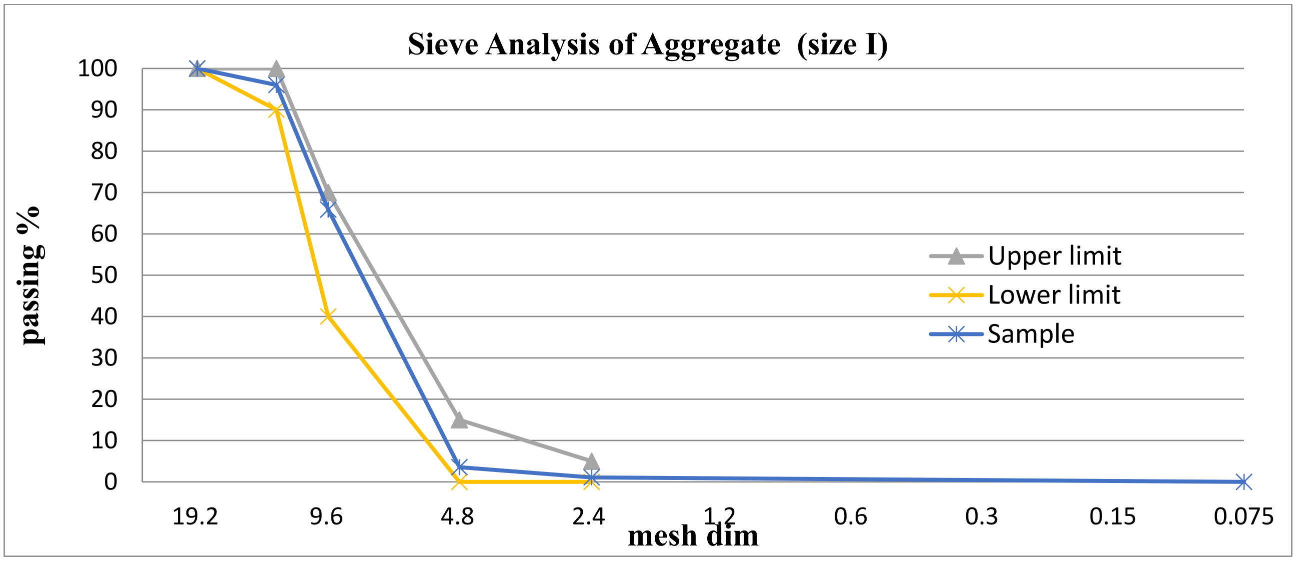

Fig.2. Sieve Analysis of Aggregate (size I)

Table 2. Physical Characteristics of Aggregate (size I) **.**

NO	Tested Property	Test specification	Limits	Measured
1	SSD (Specific Weight) t/m^3	Test 2-4**	2.5-2.75	2.67
2	moisture content %	Test 2-3**	-----	0.09%
3	Absorption Ratio %	Test 2-3**	Max 2.0%	1.82%
4	Bulk Density. t/m^3 Compacted un compacted	Test 2-5**	-----	1.641 1.505
5	Clay Lumps and Friable Particles	Test 2-11**	Max 3.0%	0.16
6	Organic Impurities	Test 2-21**	Nil	Nil
7	Abrasion (L A)	Test 2-17**	Max 35%	17.10%
8	Flakiness Index	Test 2-8**	Max 25%	17.10%
9	Elongation Index	Test 2-7**	Max 25%	9.90%
10	Chloride Content (CI)	Wet Chemical Analysis	Max 0.06%	0.031%
11	Sulfate Content (SO_3)		Max 0.40%	0.281%

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4.2.2 Aggregate (size II)

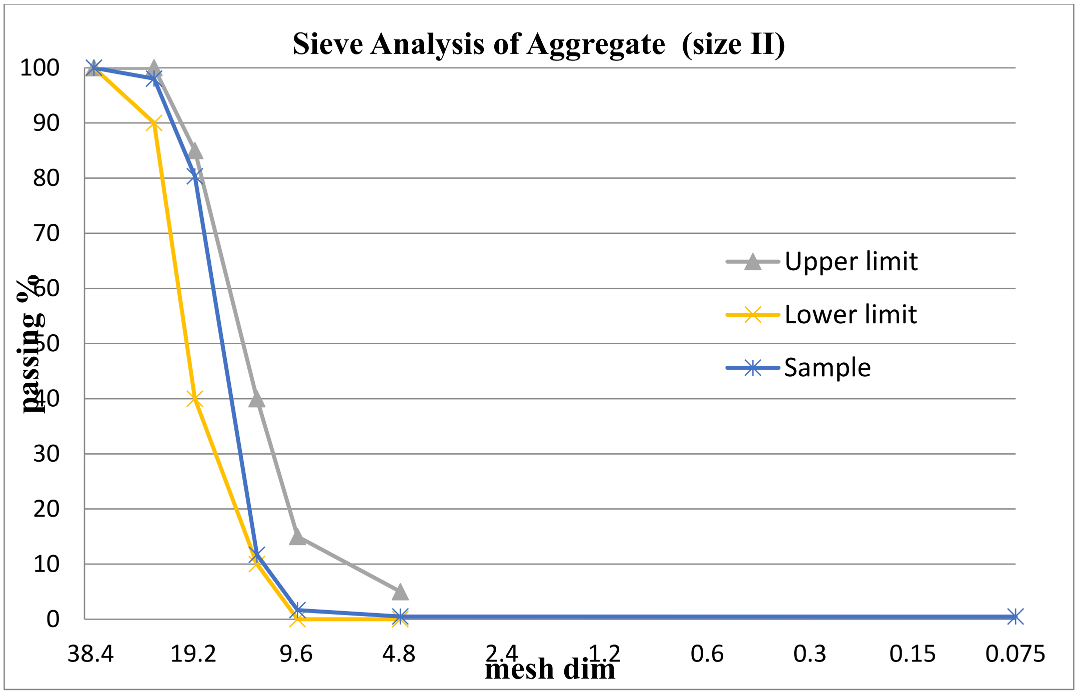

Fig. 3. Sieve Analysis of Aggregate (size II)

Table 3. Physical Characteristics of Aggregate (size II) **.**

NO	Tested Property	Test specification	Limits	Measured
1	SSD (Specific Weight) t/m^3	Test 2-4**	2.5-2.75	2.695
2	moisture content %	Test 2-3**	-----	0.05
3	Absorption Ratio %	Test 2-3**	Max 2.0%	1.48%
4	Bulk Density. t/m^3 Compacted un compacted	Test 2-5**	-----	1.627 1.539
5	Clay Lumps and Friable Particles	Test 2-11**	Max 3.0%	0.1%
6	Organic Impurities	Test 2-21**	Nil	Nil
7	Abrasion (L A)	Test 2-17**	Max 35%	17.8%
8	Flakiness Index	Test 2-8**	Max 25%	11.9%
9	Elongation Index	Test 2-7**	Max 25%	7.5%
10	Chloride Content (CI)	Wet Chemical Analysis	Max 0.06%	0.028%
11	Sulfate Content (SO_3)		Max 0.40%	0.263%

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4.2.3 Aggregate (size III)

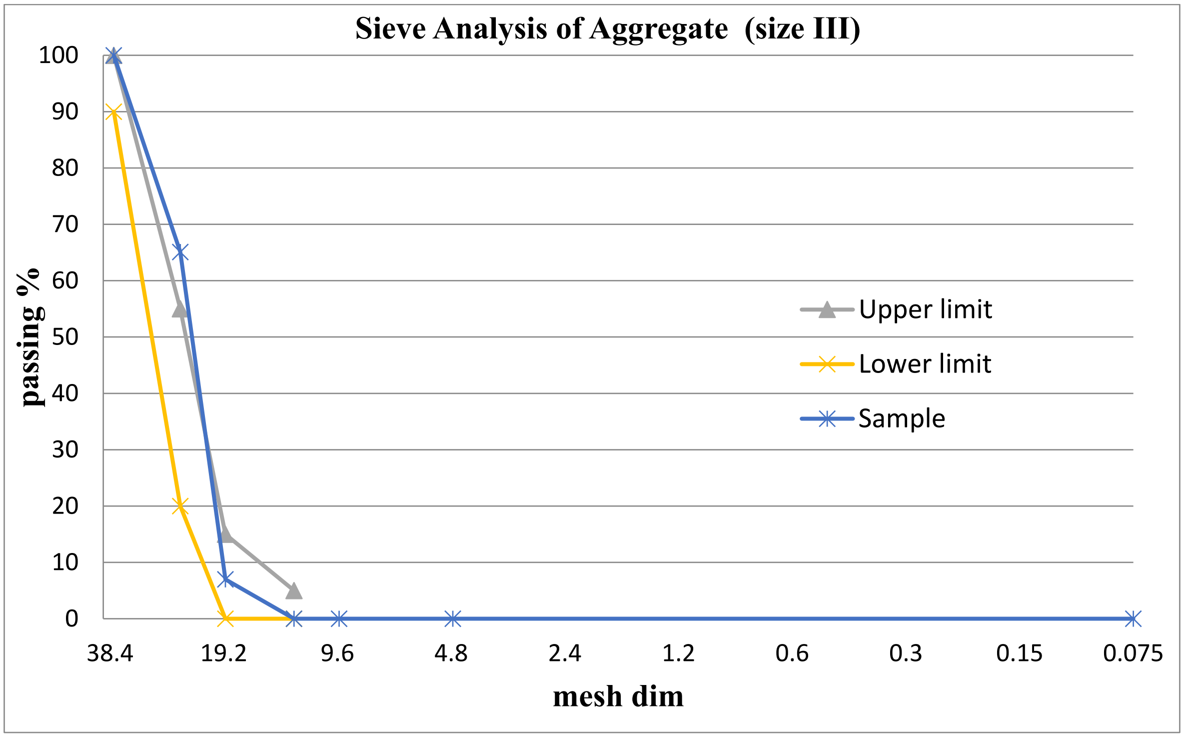

Fig. 4. Sieve Analysis of Aggregate (size III)

Table 4. Physical Characteristics of Aggregate (size III)

NO	Tested Property	Test specification	Limits	Measured
1	SSD (Specific Weight) t/m^3	Test 2-4**	2.5-2.75	2.65
2	moisture content %	Test 2-3**	-----	0.05
3	Absorption Ratio %	Test 2-3**	Max 2.0%	1.6%
4	Bulk Density. t/m^3 Compacted un compacted	Test 2-5**	-----	1.577 1.451
5	Clay Lumps and Friable Particles	Test 2-11**	Max 3.0%	0.1%
6	Organic Impurities	Test 2-21**	Nil	Nil
7	Abrasion (L A)	Test 2-17**	Max 35%	17.5%
8	Flakiness Index	Test 2-8**	Max 25%	8.5%
9	Elongation Index	Test 2-7**	Max 25%	8%
10	Chloride Content (CI)	Wet Chemical Analysis	Max 0.06%	0.023%
11	Sulfate Content (SO_3)		Max 0.40%	0.241%

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4.3 Water

The water used is tap water suitable for drinking. Tests were conducted to determine the content of chlorides, sulphates, total dissolved salts (TDS) and pH, were compiled and presented in Table 5.

Table 5. Chemical Characteristics of Water

NO	Tested Property	Limits	Measured
1	Chloride Content (CI) PPM	Max 500	58
2	Sulfate Content (so_3)	Max 300	52
3	TDS	Max 2000	235
4	PH	Min 7	7.05

4.4 Master Glenium 118

It is an innovative latest generation super plasticizer based on poly carboxylic ether (PCE) polymers and is specially engineered for ready-mix concrete. Various experiments and tests were conducted to determine the physical and chemical properties, were compiled and presented in Table 6.

Table 6. Physical and Chemical Characteristics of Master Glenium 118

NO	Tested Property	Observed/Measured
1	Appearance	Medium brown to dark brown coloured liquid
2	Specific gravity @ 25°C	1.056
3	pH value	4.5 – 6.5
4	Chloride content	“chloride-free” to EN 934

4.5 Master Air 111 EG

It is an air-entraining admixture, which creates microscopic air bubbles that are strong, small and closely spaced. These air bubbles improve the plasticity of the fresh concrete and reduce the sulphate attack and water penetration of the cured concrete. Various experiments and tests were conducted to determine the physical and chemical properties, were compiled and presented in Table 7.

Table 7. Physical and Chemical Characteristics of Master Air 111 EG

NO	Tested Property	Observed/Measured
1	Specific gravity	1.004 1.005 at 25°C
2	pH	6-7.5
3	Color	Transparent Pale Yellowish
4	Chloride content	Nil to BS 5075 :1982

4.6 Master Fiber® F 100

Poly propylene fiber is a unique technology that creates additional micro fibrils that are attached to the principle fibrillated network. These additional anchorage sites provide increased bonding between the mortar matrix and the fiber network and enhances the performance of Master Fiber F 100 product as a shrinkage and temperature (secondary) reinforcement. Various experiments and tests were conducted to determine the physical and chemical properties, were compiled and presented in Table 8.

Table 8 . Physical and Chemical Characteristics of Master Fiber® F 100

NO	Tested Property	Measured
1	Specific Gravity	0.91
2	Melting Point	320 °F (160 °C)
3	Ignition Point	1,094 °F (590 °C)
5	Absorption	Nil
6	Alkali Resistance	Excellent
7	Electrical Conductivity	Low
8	Thermal Conductivity	Low
9	Tensile Strength	60,000 psi (415 MPa)
10	Modulus of Elasticity	800 ksi (5.52 GPa)
11	Available Lengths	0.25 in. (6 mm) and 0.75 in. (19 mm)
12	Aspect Ratio	29

4.7 Glass powder

Glass powder sourced from recyclable materials was used in this study. Various experiments and tests were conducted to determine the chemical properties.

Table 9. The Average Composition of the Glass Material (%).

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
%	72.40%	1.45%	0.48%	11.50%	0.65%	13.00%	0.43%	0.09%

4.8 Cement:-

4.8.1 Portland Cement sample (CEM I 42.5) Elarish

` **Table 10.** Physical and Mechanical Characteristics of Cement Elarish.

Physical properties			
Property	Measured		limits of specification (E.S.S.-4756-1/2013)
setting time	hour	min	not less than 60 min
	2	20	
soundness	1.00 mm		not more than 10 mm
Fineness	367 m^2/kg		
mechanical properties			
Property	Measured		limits of specification (E.S.S.-4756-1/2013)
compressive strength			
2- day	22.1		not less than 10 N/mm^2
28- day	45.8		not less than 42.5 N/mm^2
			not more than 62.5 N/mm^2

4.8.2 Portland Cement sample (CEM I 42.5) Elsewedy

Table 11. Physical and Mechanical Characteristics of Cement Elsewedy**.**

Physical properties			
Property	Measured		limits of specification (E.S.S.-4756-1/2013)
setting time	hour	min	not less than 60 min
	2	15	
soundness	1.00 mm		not more than 10 mm
Fineness	364 m^2/kg		

Mechanical properties		
Property	Measured	limits of specification (E.S.S.-4756-1/2013)
Compressive strength		
2- day	21.2	not less than 10 N/mm^2
28- day	43.8	not less than 42.5 N/mm^2
		not more than 62.5 N/mm^2

5. EXPERIMENTAL WORK

An experimental study was conducted to evaluate and compare the improvements in the physical and mechanical properties of Rigid Pavement. This was achieved by introducing glass powder.

Table 12. Mix Components

NO		Control	5%	10%	15%	20%
Cement (kg)		420	420	420	420	420
water (lit)		160	160	160	160	160
sand (kg)		660	639	618	597	576
crushed stone	size I	440	440	440	440	440
	size II	420	420	420	420	420
	size III	385	385	385	385	385
MASTER Gelinium118 (lit)		4	4	4	4	4
MASTER Air 111 (lit)		0.2	0.2	0.2	0.2	0.2
poly fiber (gm)		900	900	900	900	900
Glass Powder (kg)		0	21	42	63	84

6. RESULTS

Two different types of cement were used during the tests with different proportions of glass powder. The experimental results were obtained after incorporating all the previously mentioned additives into the samples. They were plotted; presented on graphs and discussed here, as follows:

6.1 Slump test

It is observed that with an increase in the percentage of adding glass powder, the value of the concrete slump increases, which indicates an increase in the workability of the concrete.

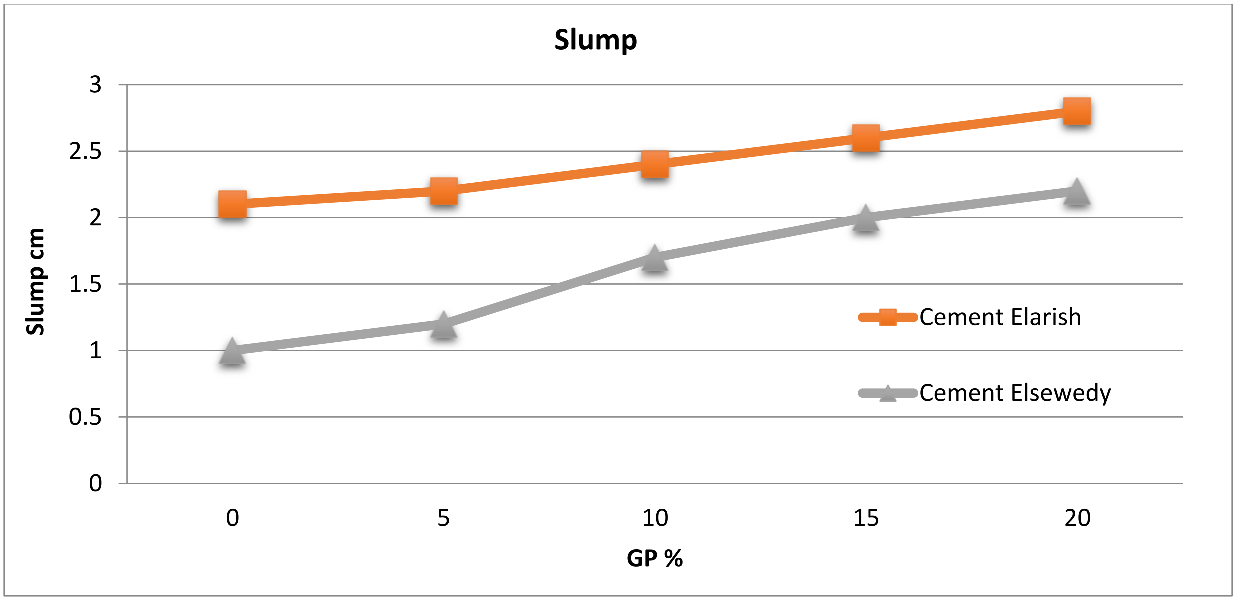

Fig. 5. Slump results

6.2 Air Content

It is observed that with an increase in the percentage of adding glass powder, the value of the concrete air content increases, which indicates an increase in the workability of the concrete.

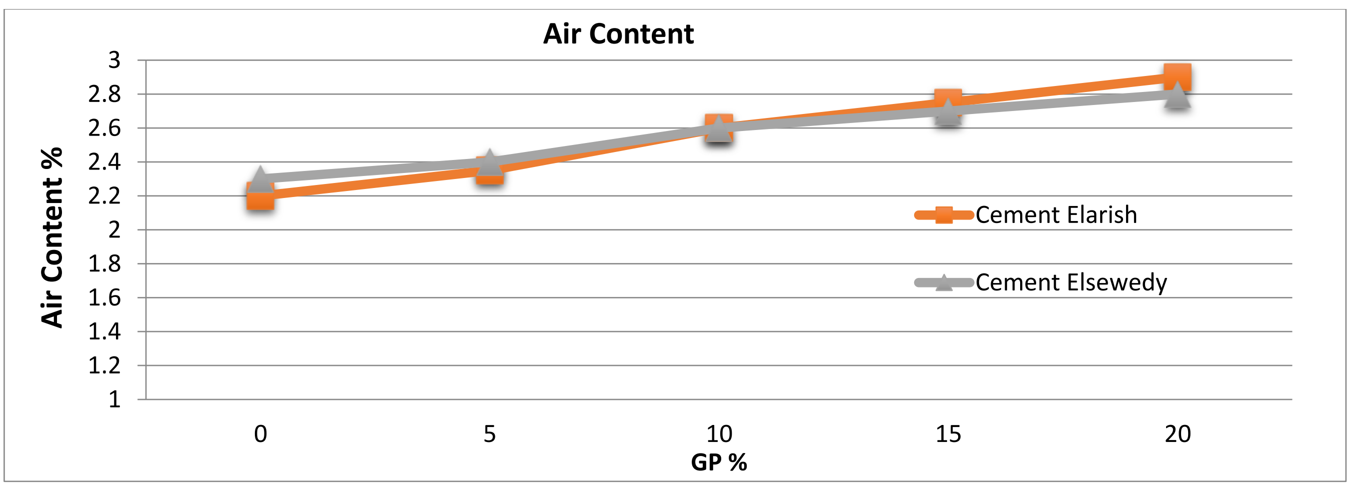

Fig. 6. Air Content Value for Cement Elarish

6.3 Compressive strength.

The results show that the optimal glass powder content for maximum concrete strength is 15% with Elarish cement and 10% with Elsewedy cement, beyond which strength declines. After 28 days, the compressive strength with Elarish cement increased by 16.57% (from 507.73 to 591.89 kg/cm²) at 15% glass powder, while with Elsewedy cement, it increased by 13.28% (from 472.5 to 535.28 kg/cm²) at

10% glass powder.

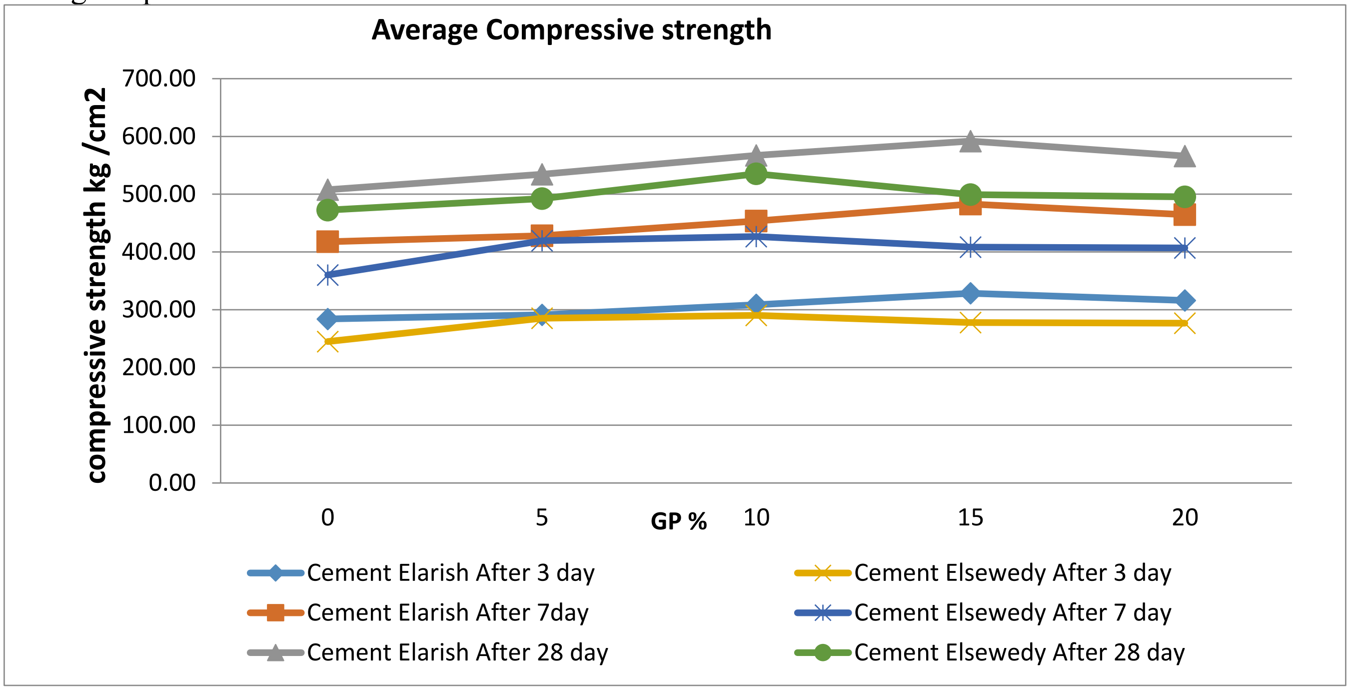

Fig. 7. Average Compressive strength values

6.4 Flexural strength :-

The maximum flexural strength occurs at 15% glass powder with Elarish cement and 20% with Elsewedy cement, beyond which strength declines. After 28 days, flexural strength with Elarish cement increased by 10.47% (from 95.2 to 105.17 kg/cm²) at 15% glass powder, while with Elsewedy cement, it rose by 2.5% (from 94.3 to 96.7 kg/cm²) at 10% glass powder.

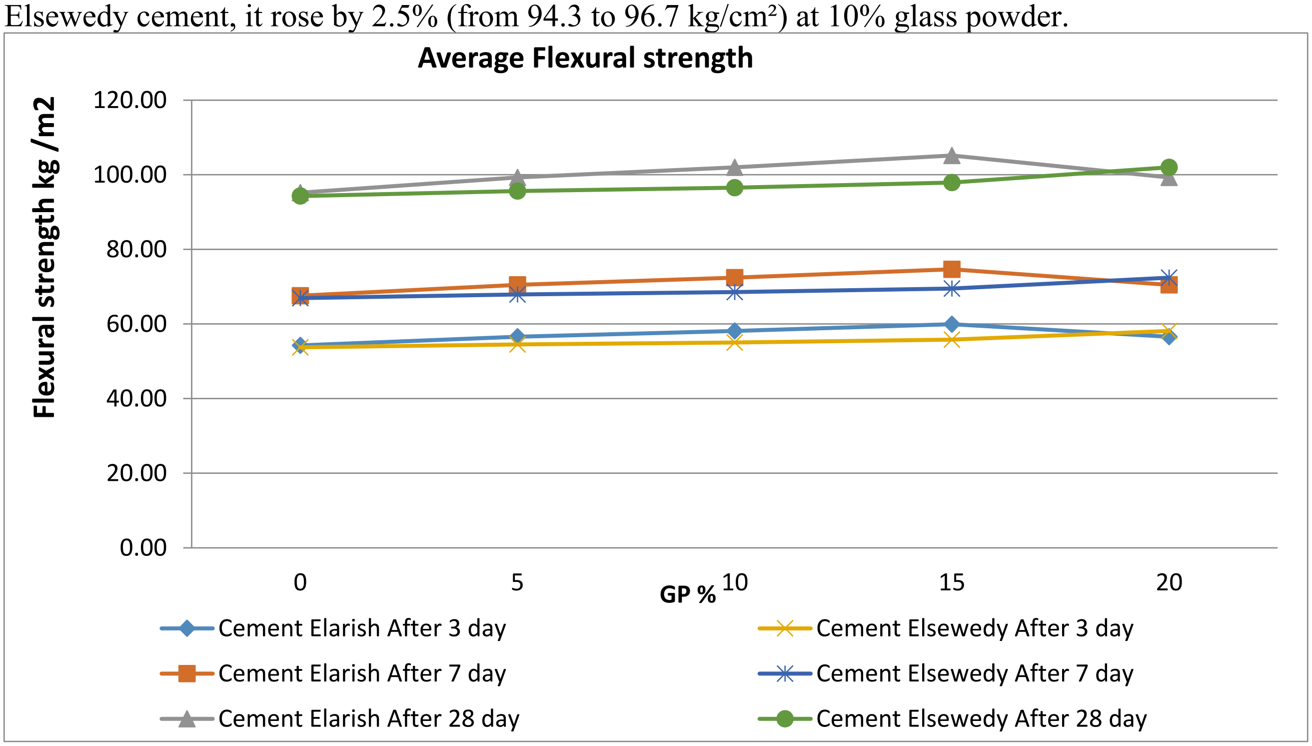

Fig. 8. Average Flexural strength value

6.5 Absorption.

It is observed that with an increase in the percentage of adding glass powder, the value of the concrete absorption decrease.

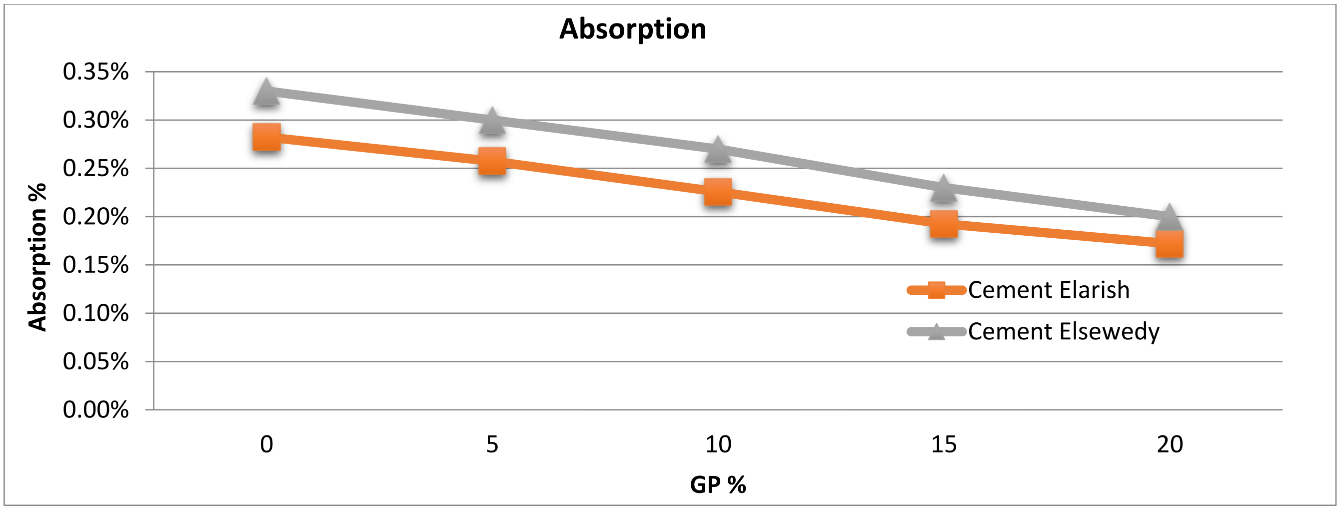

Fig. 9. Absorption values

6.6 Abrasion.

The results indicate that the minimal abrasion of concrete occurs at around 10% glass powder this is when using cement Elarish and Elsewedy . Beyond 10% glass powder the abrasion of concrete increase.

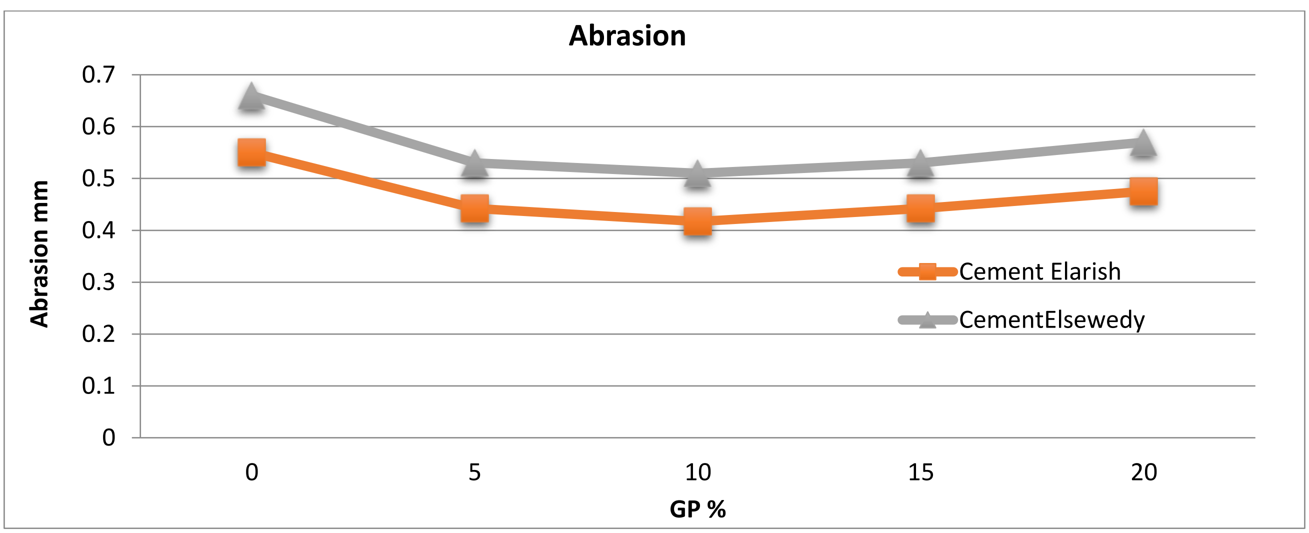

Fig. 10. Abrasion value

6.7 X-Ray Diffraction (XRD).

The experimental investigation was conducted on two sets of samples: one containing 0% glass powder and the other incorporating 15% glass powder. The latter was identified as the optimal replacement percentage based on its superior performance in key mechanical properties, including compressive strength, flexural strength, and wear resistance. The cement utilized in the preparation of these samples was sourced from the Arish region.

To provide a comprehensive analysis it is clear that the main compounds prevailing in both samples are Dolomite, Quartz, Portlandite and Calcite, the results for the 0% glass powder sample were documented in Table 13 and illustrated in Figure 11, while the data corresponding to the 15% glass powder sample were presented in Table 14 and depicted in Figure 12. These tables and figures serve to highlight and compare the differences in the compositional characteristics and mechanical performance of both sample sets.

Furthermore, to gain insights into the chemical composition and elemental distribution of the materials, an X-ray fluorescence (XRF) analysis was performed. This analytical approach was crucial in understanding the role of glass powder in enhancing the material's properties and providing a detailed comparative evaluation of the two sample types.

Table 13. XRD for sample 0%

Ref. Code	Mineral Name	Chemical Formula
96-900-3509	Dolomite	Ca3.00 Mg3.00 C6.00 O18.00
96-101-1160	Quartz low	Si6.00 O6.00
96-901-0900	Portlandite	Ca1.00 O2.00 D2.00
96-101-0929	Calcite	Ca6.00 C3.00 O18.00

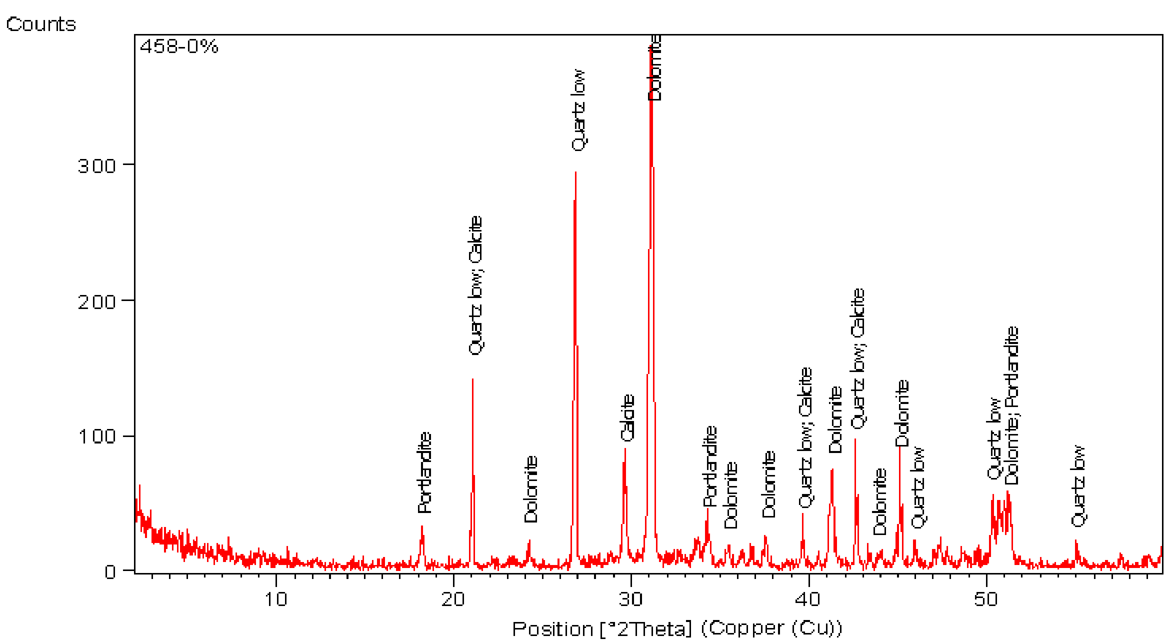

Fig .11. XRD for sample 0%

Table 14. XRD for sample 15%

Ref. Code	Mineral Name	Chemical Formula
96-900-3515	Dolomite	Ca3.00 Mg3.00 C6.00 O18.00
96-101-1177	Quartz low	Si6.00 O6.00
96-900-1298	Calcite	Ca5.62 Mg0.38 C6.00 O18.00
96-901-0900	Portlandite	Ca1.00 O2.00 D2.00

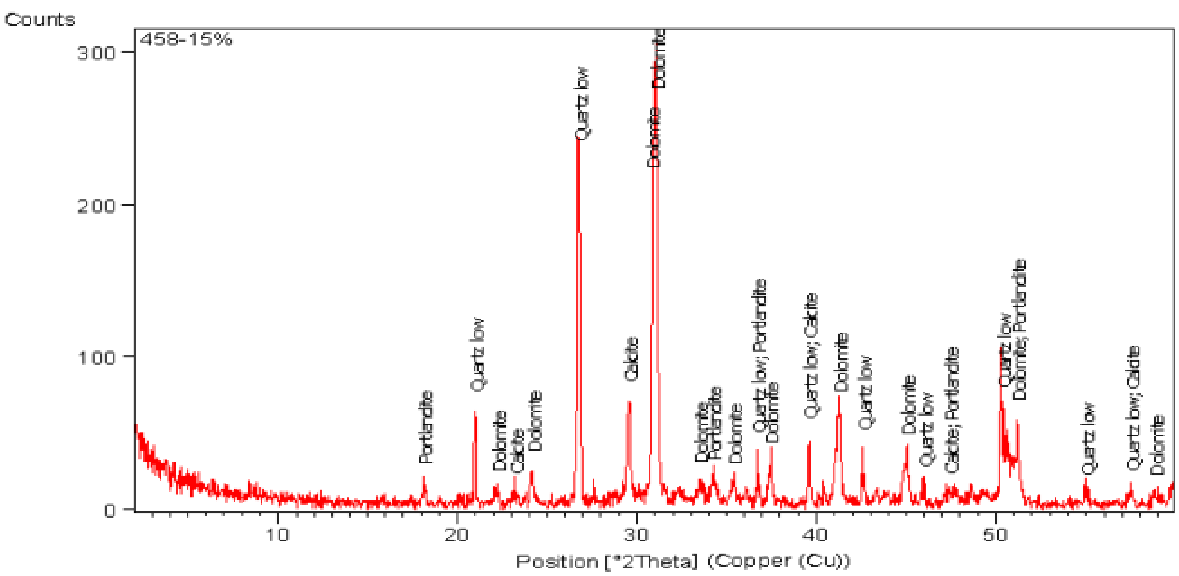

Fig. 12. XRD for sample 15%

6.8 X-Ray Fluorescence (XRF).

The test was carried out on two distinct sets of samples: one with no glass powder (0%) and the other incorporating 15% glass powder. The experimental results revealed significant variations in the chemical composition between the two sample groups. Specifically, the sample containing 15% glass powder exhibited notable increases in silica (SiO_2), iron oxide (Fe_2O_3), and magnesium oxide (MgO) compared to the 0% glass powder sample. Conversely, a noticeable reduction in calcium oxide (CaO) was observed in the 15% glass powder sample relative to its counterpart.

These findings suggest that the inclusion of glass powder as a partial replacement material introduces compositional changes that can significantly influence the chemical and possibly mechanical properties of the material. The increased presence of silica, iron oxide, and magnesium oxide in the 15% glass powder sample could enhance certain properties, such as durability, resistance to chemical degradation, or mechanical performance, depending on the application. However, the reduced calcium oxide content may impact hydration processes, setting time, or strength development, particularly if the material is intended for use in cementitious applications.

Overall, this compositional analysis highlights the potential of glass powder as a sustainable additive, while also emphasizing the need for careful optimization to balance the chemical and physical characteristics required for specific engineering applications. This trend clarifies the compressive strength enhancements for 15% WGP contained concrete with respect to control specimens with 0% WGP. A previous study stated that the intensity of CH content decreased as the amount of WGP increased due to the consumption of CH in the pozzolanic reaction with silica in the secondary hydration reaction.

Table 15. XRF Analytical Spectra of Elements Representing 0% and 15% GP

no	sample	0% WGP	15% WGP
3	SiO_2	16.43%	20.37%
4	TiO_2	0.05%	0.05%
5	Al_2O_3	1.03%	1.19%
6	Fe_2O_3	1.37%	1.57%
7	MnO	0.04%	0.03%
8	MgO	11.09%	11.65%
9	CaO	41.89%	37.88%
10	Na_2O	0.02%	0.03%
11	K_2O	0.11%	0.12%
12	P_2O_5	0.02%	0.02%
13	Cl	<0.01%	<0.01%
14	SO_3	0.93%	0.84%
15	LOi	26.73%	25.93%

6.9 Scanning Electron Microscope (SEM)

The scanning electron microscope (SEM) images for the control specimen and the specimen containing 15% waste glass powder (WGP) are presented in Figure 13 (a, b, c, and d). A detailed examination of these images reveals notable differences in the microstructural characteristics between the two types of specimens. For the plain concrete without WGP replacement (Figure 13a and b), large pores and visible cracks dominate the microstructure. These defects are indicative of a less compact and more heterogeneous structure, which could negatively impact the mechanical properties of the material. In contrast, the SEM images for the concrete specimen with 15% WGP replacement (Figure 13c and d) display a denser and more homogeneous microstructure. The inclusion of WGP appears to significantly reduce the presence of large pores and cracks, resulting in a more compact and refined structure.

This improvement can be attributed to the pozzolanic activity of WGP. As a supplementary cementitious material, WGP reacts with calcium hydroxide during the hydration process to form additional calcium silicate hydrates (C-S-H), which enhance the binding properties of the matrix. This reaction not only reduces the pore size and distribution but also improves the overall density and homogeneity of the concrete structure.

The enhanced microstructure observed in the WGP-containing specimens correlates directly with an increase in compressive strength. By replacing a portion of the cement with WGP, the material benefits from improved particle packing and reduced porosity, leading to superior mechanical performance. These findings underscore the potential of WGP as an eco-friendly and effective partial cement replacement that improves both the sustainability and structural integrity of concrete.

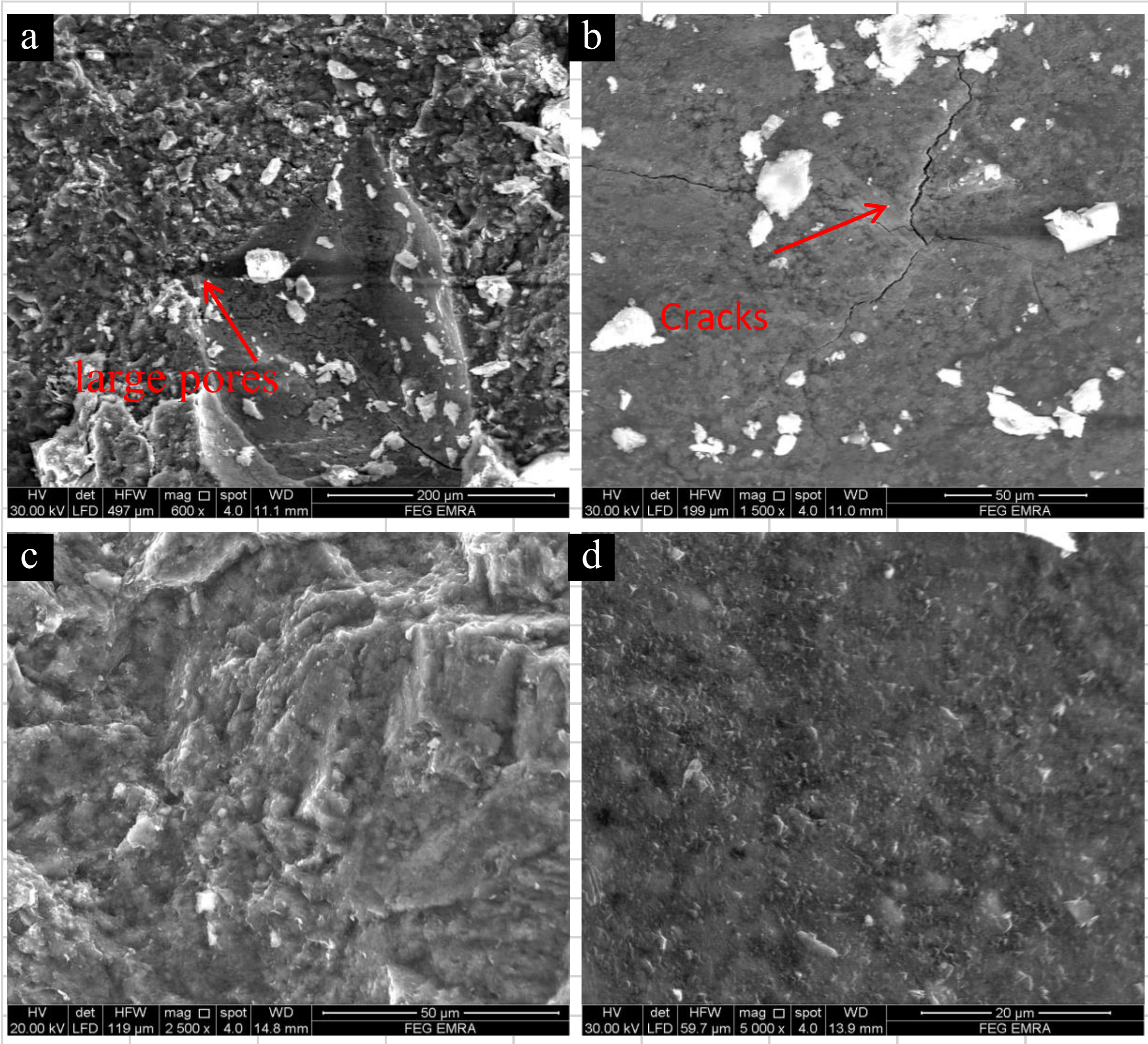

Fig. 13: Scanning Electron Microscopy (SEM) images of the test samples: (a, b) correspond to the specimen with 0% glass powder, while (c, d) represent the specimen containing 15% glass powder.

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Based on the findings of this research, several conclusions can be drawn regarding the use of glass powder in concrete mixes: Firstly, glass powder has been identified as an effective additive for enhancing concrete mixes. Its incorporation into the concrete mix increases the slump value and the content of entrapped air, which collectively contribute to improved workability. Moreover, the use of glass powder is associated with a reduction in the absorption value of the concrete, indicating enhanced durability. When 15% glass powder is used with Cement Elarish, a significant improvement in the concrete's mechanical properties is observed. Specifically, the compressive strength of the concrete is increased by 16.57%, while the flexural strength is enhanced by 10.47%. In addition, when

10% glass powder is used with Cement Elarish, the abrasion value of the concrete is reduced by 24.18%, further demonstrating its beneficial effects on durability. Similarly, the use of 10% glass powder with Cement Elsewedy results in an increase in the compressive strength by 13.28%, and an improvement in the flexural strength by 2.5%. These findings suggest that glass powder is a valuable additive for improving the strength and durability of concrete, particularly when used in specific proportions with different types of cement. An experimental study compared samples with 0% and 15% glass powder through an X-ray test, identifying 15% as the optimal replacement for improved compressive strength, flexural strength, and wear resistance and revealed that the key compounds in both samples included Dolomite, Quartz, Portlandite, and Calcite.

The XRF revealed that 15% glass powder increased silica, iron oxide, and magnesium oxide while reducing calcium oxide. These compositional changes enhance durability and mechanical performance but may affect hydration and strength development. The findings highlight glass powder's potential as a sustainable additive, with pozzolanic reactions reducing calcium hydroxide and improving compressive strength in 15% WGP concrete.

SEM images reveal that adding 15% WGP creates a denser, more homogeneous structure compared to plain concrete (0% WGP), which has large pores and cracks. The pozzolanic activity of WGP reduces pore size, enhances density, and increases compressive strength, highlighting its effectiveness as a sustainable cement replacement.

7.2 Recommendations

Based on the findings of this research, we strongly advocate for the use of glass powder to enhance the performance of concrete, particularly in abrasion-resistant concrete utilized in rigid pavements. This recommendation is especially pertinent given the increasing demand for infrastructure capable of supporting the heavy loads associated with societal and urban expansion, both globally and in Egypt. Considering its availability and low cost, we recommend the widespread adoption of glass powder in concrete production. This can be facilitated by incorporating simple modifications to concrete plants, such as the addition of glass crushers and sieve meshes to achieve the desired gradation. These adjustments would improve the sand fineness modulus, thereby enhancing concrete's abrasion resistance, workability, and efficiency. Additionally, the use of glass powder allows for a reduction in the water-cement ratio and minimizes the reliance on costly chemicals traditionally used to maintain concrete workability.

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