

Compressive Strength and Water Absorption of Mortar Using Windscreen Glass Waste Powder (WGWP) As A Sustainable Sand Replacement

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Abstract

In many developing countries today, there is a growing shortage of landfill sites for waste disposal. To address this issue and reduce environmental pollution, the reuse of glass waste as a substitute for sand in concrete production has been proposed. This study examines the effects of incorporating windscreen glass waste powder (WGWP) as a partial replacement for sand in mortar mixtures, focusing on compressive strength and water absorption performance. The mortar mix was designed with a ratio of 1:3 (cement to sand) and a water-cement ratio of 0.5. Sand was partially replaced with WGWP at levels of 10%, 20%, and 30%, and the specimens were tested after 7, 14, and 28 days of curing. The results showed that mortars containing WGWP exhibited improved performance compared to the control sample. Specifically, the addition of 30% WGWP led to enhanced compressive strength and reduced water absorption, indicating the potential of recycled windscreen glass as a viable alternative to natural sand in mortar production.

Key Words: Sand Replacement; Windscreen Glass Waste Powder; Compressive Strength; Water absorption

1.0 Introduction

Sand output has significantly increased as a result of Malaysia's rapid development, which has had a negative influence on the environment. With numerous construction projects taking place across the country, the demand for construction materials, particularly sand, continues to rise. However, sand mining often results in erosion, especially in environmentally sensitive or high-risk areas. This indirectly results to undesirable impact to the local environment including human and wildlife. Supporting this, Wang, Y. M. A. (2015) predicted that tonnes of trash glasses will be produced annually all around the world as a result to fast population expansion and urbanisation.

Glass waste is one of the common materials found in any dumping areas. The glass wastes can be categorized by their different chemical compositions and the physical properties. Distinct kinds of glasses lead to distinct glass waste components. Subsequently, distinct kinds of glass trash exhibit unique reactions to the mixture. Typically, the glass wastes are sorted by their types and colours. Vasudevan & Pillay (2013) highlighted that, during the recycle process or at the disposal sites, the glass wastes are sorted such as green and black bottles, brown, glass for cathode ray, car windshields, colourless bottles and glass building materials. Life span of glass differs and it depends on its types. However, there are limited glass recycling methods available in the market. The methods usually focus on recovery of the glass wastes. Glass recovery process includes crushing or melting process before it can be used. Commonly, the disposal areas do not classify glass wastes based on their properties. Consequently, this glass finally ends up to be reused for other limited purposes and some other end up in the landfill (Bhandari & Tajne, 2013).

Glass is produced via a mixing process of certain materials soda silica, ash and calcium carbonate (CaCO_3). After being melted at a high temperature and allowed to cool, all of these materials create a fairly translucent solid that does not crystallize. Glass has properties comparable to those of real sand when it is broken down into a powder that resembles sand. Water absorption method is an efficient way to determine the moisture content of the specimens after casting. Specimen's quality can be identified based on its absorbency level. This method closely related to the specimen's porosity level. It is important to stress that lesser absorbency level indicates a higher quality of the mortar. A high-quality mortar

absorbs a minimum amount of water during the immersion process in a certain period of time. Besides that, Nassar, R.-U.-D., & Soroushian, P. (2011) highlighted that the water absorption may reduce and lowering down the mortar cube, the volume of voids and results to low absorption of water due to the mortar itself. The workability increased when the glass powder increase on the mortar or concrete (Shekhawat and Aggarwal, 2014).

Windscreen glass waste has contributed to a large sum of solid wastes found on disposal site. Car accidents and disposal of cars are major contributors to the windscreen glass waste. Windscreen glasses are typically disposed to the landfill sites and recycle centres. The processes of recovering and recycling the windscreen glass waste involves crushing, melting and cooling processes. However, these processes call for a huge amount of money. Furthermore, it is inefficient since not all types of windscreen are recyclable. But, if all the wastes are just being disposed without recycled, the massive amount of waste will demand for an enormous size of disposal site. As a result, this scenario affects the environment in the most unpleasant way Du et. al, (2014).

It is not widely known that windscreen glass waste shares similar characteristics with natural sand, making it a potential alternative construction material. However, before it can be utilized, the windscreen glass waste needs must be processed into windscreen glass waste powder (WGWP). WGWP contains silica that works as natural sand on chemical composition. This silica contributes to pozzolanic activity, enhancing the material's performance in cement-based applications. The silica content in a mix with 20% windscreen glass waste (GW) may be comparable to the calcium hydroxide content, resulting in an optimal pozzolanic reaction (Kushartomo et al., 2015). Hence can be used to substitute the natural sand that possesses similar properties. The purpose of this study is to determine the ideal amount of windscreen glass waste that improves the performance of mortar and to assess the compressive strength and water absorption of mortar with partial sand substitution using particular mix proportions.

2.0 Methodology

The car windscreen glass came from local workshops in Terengganu, Malaysia. The Los Angeles machine was used to grind windscreen glass up to 5000 revolutions using 12 steel rods to produce the automotive (WGWP). Figure 1 shows the flow of the preparation of WGWP.



Figure 1: Preparation of automotive windscreen glass waste powder (WGWP)

A total of 120 mortar cube specimens, each measuring 50 mm x 50 mm x 50 mm, were used in the investigation. The mortar mix's water-to-cement (w/c) ratio was 0.5 and its cement-to-sand (C:S) ratio was 1:3. In order to incorporate different percentages of GW, three mix proportions were chosen: 10%, 20%, and 30% by weight of sand. Until the day of the compressive strength test, which was conducted at 7, 14, and 28 days, the mortar cubes

were water-cured. The American Society for Testing and Materials' ASTM C109 (2013) was followed in the compressive strength test, and ASTM C1403-13 (2013) was followed in the water absorption test. At 7, 14, and 28 days, cube specimens of 50 mm x 50 mm x 50 mm were put to the test. For every batch, five replicates were used.

3.0 Results and Discussion

In order to assess the impact of using waste glass powder (WGWP) in mortar mixtures as a partial substitute for sand, the outcomes of the compressive strength and water absorption tests are covered in detail below.

3.1 Compressive Strength

Table 1: The average strength value for each curing day

SAND REPLACEMENT BY WASTE GLASS POWDER	COMPRESSIVE STRENGTH (N/mm ²)		
	7 days	14 days	28 days
CONTROL	31.20	45.69	50.59
10%	29.65	32.09	40.00
20%	41.49	49.27	50.45
30%	50.60	51.50	57.97

The results indicated that using 30% WGWP improved the properties of the mortar. Although the specimens with 30% WGWP contained only a single material, they still demonstrated positive effects and performed better than conventional mortar.

Figure 2 also indicates that the average compressive strength for day 7 of control specimen was 31.20 N/mm² and the 30% of WGWP increased to 50.60 N/mm² which 38% higher compared to the control specimen. On day 14, the control specimen recorded a compressive strength of 45.69 N/mm², which is 11% lower than the 30% WGWP specimen at 51.50 N/mm². By day 28, the 30% WGWP specimen reached 57.97 N/mm², approximately 13% higher than the control specimen at 50.59 N/mm². These results indicate that incorporating 30% WGWP enhances the mortar's compressive strength at both early and later stages of curing.

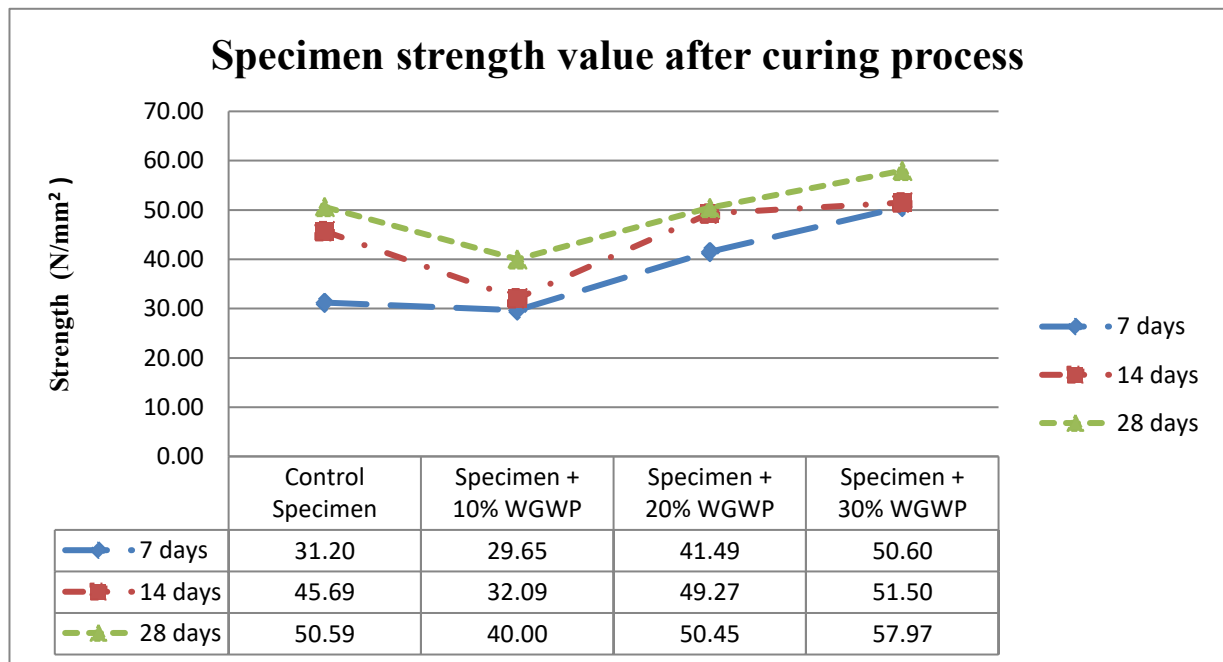


Figure 2: The graph of specimen strength value after curing process

Additionally, on day seven, the mortar mix containing 10% windscreen glass waste powder (WGWP) had an average compressive strength of 29.65 N/mm² and 31.20 N/mm², respectively, which was somewhat less than that of the control specimen. On day 14, the strength also showed a slight decrease, with averages of 32.09 N/mm² for the 10% WGWP specimen and 45.69 N/mm² for the control. However, by day 28, the compressive strength of the 10% WGWP mix dropped more significantly compared to the control, recording averages of 40.00 N/mm² and 50.59 N/mm², respectively. This reduction is attributed to the lower quantity of WGWP used in the mix. Therefore, it can be concluded that incorporating 10% WGWP in the mortar results in lower compressive strength compared to the control mix.

Furthermore, on day 7, the specimen with 20% WGWP had an average compressive strength of 41.49 N/mm², while the control specimen had an average of 31.20 N/mm². This indicates that the 20% WGWP mix had approximately 25% higher strength than the control. On day 14, the compressive strength of the 20% WGWP mix continued to increase, recording 49.27 N/mm² which about 7% higher than the control specimen at 45.69 N/mm². By day 28, the strength of the 20% WGWP mix was nearly equal to that of the control, with values of 50.45 N/mm² and 50.59 N/mm², respectively. The trend suggests that the addition of 20% WGWP contributes to improved compressive strength, and this improvement continues with increasing WGWP content.

Figure 2 shows the line chart of average strength for each curing day. It was highlighted that the strength of mortar depends on the period of the curing process. It showed that the usage 30% of WGWP gave a highest strength of specimen. The average percentage of strength for all different days of curing process for the 10% of WGWP was lower than the control specimen. In contrast, the average strength percentage for the specimen using 20% WGWP abruptly jumped by 15% compared to the 10% WGWP. The average percentage of strength rose by about 10% for specimens that used 30% WGWP. Figure 2 summarizes that the mortar mix exhibited greater strength when 30% WGWP was substituted.

3.2 Water Absorption

Based on Table 2, the results indicate that the mortar with 30% replacement of windscreen glass waste powder exhibited the lowest water absorption compared to other mortar samples. This suggests that the 30% replacement level enhances the durability of the mortar by reducing the degree of water penetration. The findings support the conclusion that incorporating glass waste can effectively reduce water absorption in mortar (Omoniyi, Akinyemi, Fowowe, 2014).

Table 2 : Water Absorption Test Due to Curing Age

Percentage of Replacement Windscreen Glass Waste Powder	Curing Age	Time (min)			
		30	60	120	240
0%	7	6.21	8.26	7.93	7.84
	14	5.66	7.33	7.66	7.76
	28	5.65	7.97	8.39	8.35
10%	7	5.49	7.58	7.76	7.82
	14	5.44	7.15	7.21	7.21
	28	5.71	7.46	7.79	7.77
20%	7	5.4	7.18	7.58	7.65
	14	4.63	6.15	6.46	6.52
	28	5.06	6.86	7.18	7.26
30%	7	5.07	6.79	7.28	7.36
	14	4.39	5.66	5.93	6.03
	28	4.54	6.44	6.78	6.85

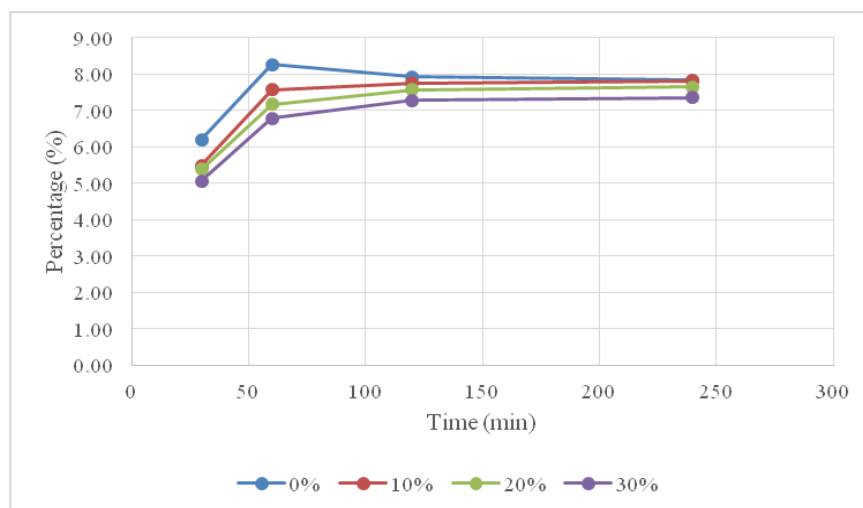


Figure 3 : Water Absorption Percentage of Glass Waste Mortar at 7 days of Curing

Figure 3 shows that the highest water absorption for the control mortar sample occurred at 60 minutes, while the peak for other samples was observed at 120 minutes during the immersion test, followed by a decline toward the end of the test. However, the control sample consistently exhibited higher water absorption compared to all other mixes. The graph clearly demonstrates that all samples containing windscreen glass waste powder had lower water absorption percentages than the control.

The results indicate that the mortar sample with 30% replacement of glass waste powder had the lowest water absorption percentage compared to the other replacement levels and the control sample. This suggests that the 30% replacement level provides superior resistance to water absorption.

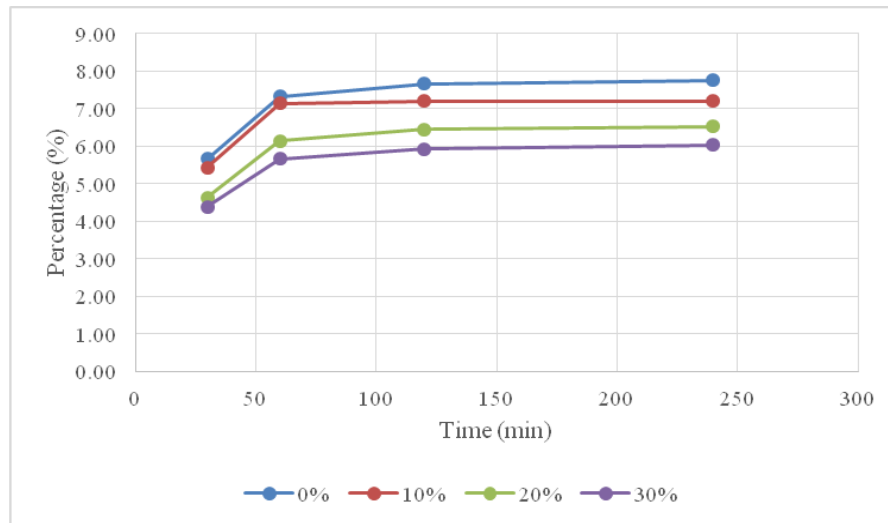


Figure 4 : Water Absorption Percentage of Glass Waste Mortar at 14 days of Curing

The water absorption findings for the glass waste mortar samples after 14 days of curing are shown in Figure 4. The pattern of results is similar to that observed at 7 days, although a slight reduction in water absorption percentages was noted, likely due to the extended curing period.

As with the earlier results, the control sample exhibited the highest water absorption percentage. In contrast, the mortar sample with 30% glass waste replacement consistently showed the lowest water absorption compared to the other replacement levels.

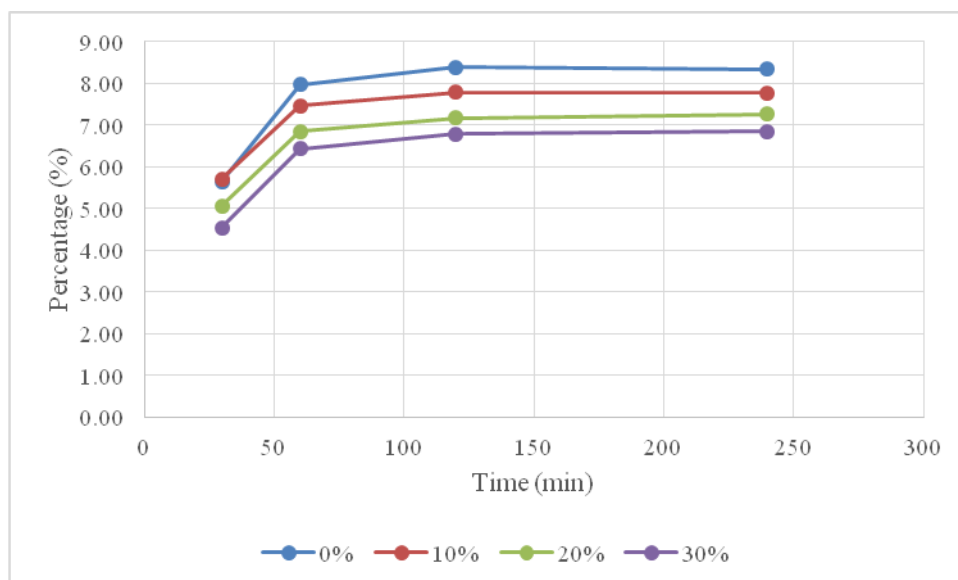


Figure 5: Water Absorption Percentage of Glass Waste Mortar at 28 days of Curing

Figure 5 presents the water absorption results of the mortar samples at 28 days of curing. The results are consistent with those from the 7-day and 14-day curing periods, showing similar trends in water absorption behaviour across all samples.

In the present study, the results demonstrate that mortar samples with 30% glass waste replacement were more resistant to water absorption than the control samples and samples with 10% and 20% glass waste replacement. Specifically, the 30% replacement samples demonstrated the lowest degree of water absorption.

In comparison to mortar samples and control samples with lesser replacement percentages, this study found that 30% substitution of WGWP in mortar produced the lowest percentage of water absorption. This outcome demonstrates that, when compared to other samples, the mortar sample containing 30% replacement glass waste powder has effectively attained the best water absorption.

4.0 Conclusions

This study aims to investigate the relationship between the percentage of waste glass powder (WGWP) and the compressive strength and water absorption levels of mortar. The findings have demonstrated the impact of WGWP substitution on the overall performance of the mortar. Based on the results, the following conclusions can be drawn:

- i. The compressive strength of the mortar with 30% windscreen glass waste powder (WGWP) replacement was the highest among all mix proportions (10%, 20%, and 30%), with strength increasing progressively with longer curing periods.
- ii. The performance of mortar with sand partially replaced by windscreen glass waste powder (WGWP) was significantly better than that of conventional mortar, within the tested replacement levels of 10%, 20%, and 30%. The results showed a progressive increase in compressive strength with higher WGWP content. This indicates that incorporating WGWP can enhance the compressive strength of mortar compared to control specimens. Among the tested proportions, the optimum WGWP content for achieving the highest compressive strength was 30%.
- iii. In the water absorption test, control sample has proven to achieve the highest percentage of water absorption compared to the specimens containing 10%, 20% and 30% of WGWP substitution. Moreover, increasing the percentage of WGWP in the mortar resulted in a reduction in water absorption. These findings indicate that incorporating WGWP into mortar helps to reduce the percentage of water absorption. Hence, durability of the mortar is enhanced.
- iv. A higher percentage of WGWP leads to a lower water absorption level, indicating improved durability of the mortar. Substitution of sand with WGWP can be considered as an environmental friendly effort towards green products. However, further research need to be carried out to validate its reliability and practical application. Future studies could explore additional variables, such as extended curing periods and higher levels of glass waste substitution.

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