INVESTIGATION STUDY ON DURABILITY OF GLASS RESHAPE CONCRETE: PROTECTING TO ACID ATTACK

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Abstract

In this study, the water permeability, consistency, and density of architectural mortar containing varying amounts of glass sand as fine aggregate are investigated and there relevance. Instead of being utilized as a component of white cement, metakaolin (MK) was employed as supplemental cementations material (SCM) in an effort to mitigate the effects of alkali-silica reaction in concrete with specific environmental factors. Basis of observations and evaluation of concrete with the help of Scanning Electron Microscope in order to visualize the microstructure of the glass and concrete. The findings of the experiments indicated that the permeability of the mortar rose with the amount of glass powder, and that it reached its optimum at a glass waste powder concentration of around 60–80%. The optimal amount of MK varied depending on the percentage of glass sand, and a larger amount of MK was necessary when the glass powder content reached 60%. In addition, there was an inverse relationship between the amount of glass sand added to the mortar and the consistency and density of the concrete.

keywords: *Glass Reshape, Concrete, Acid Attack , waste glass powder*

Introduction

Waste glass is one of the most significant components of municipal solid waste (MSW), which has resulted in a significant increase in the cost of disposal in a great number of cities throughout the world [1]. Glass waste was responsible for 4.6% of municipal solid waste in the United States in 2010 [2]. Within the European Union (EU) means 1kg per capita , the amount of waste glass generated in 2014 was 18.5 million tonnes [3]. In 2010, the amount of waste glass generated in Hong Kong was over 370 tonnes per day, however only 3.3% of it was recycled [1]. The remaining waste glass was dumped in landfills. In China, the total quantity of waste glass was about 18.8 million tonnes in 2018, including 9 million tonnes of flat glass, which accounted for 48.9% of the total [4]. On the one hand, the varying compositions of the glasses and the different melting points of the glasses create a substantial amount of variation, which makes it difficult to remelt the mixes. The process of separating the various kinds of waste glass was the most significant barrier to recycling [5, 6], since it is more cost effective to dispose of waste glass [5]. On the other hand, glass does not break down when it is buried in landfills; hence, burying waste glass in landfills is not a key answer for the problem of waste glass. Because more than 70 percent of glass is composed of silica dioxide ($SiO2$) lead oxide and aluminum oxide, recycling used glass via the construction industry is one technique that may be considered [5]. Accordingly, there are two applications for recycling shattered waste glass, and both applications are determined by the particle size of the waste glass. The first use uses glass powder as a supplemental cementitious material (SCM) to replace cement, and the second application uses glass cullet to replace natural aggregates in concrete or mortar [7]. There has been a significant amount of investigation on the effects that discarded glass has on the characteristics of concrete and mortar. There have been a significant number of research that have concentrated on the alkali-silica interaction that occurs during the hydration of cement as available alkali metal ions are present water [7,8]. For instance, in concrete made with 100% waste glass aggregate, ground granulated blast furnace slag (GGBS) can be used to partially replace white cement in order to decrease the alkali-silica reaction and improve the performance of the concrete. This includes the working performance, flexural strength at 28 days, dry shrinkage, alkali-silica reaction risk, and acid resistance of the concrete [9].

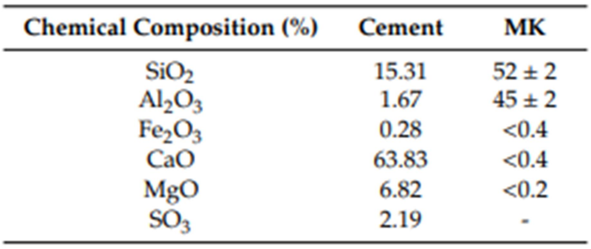
Glass powder in glass aggregate concrete has features that has been comparable to those of SCM [8,10,11], but it has superior bending strength, acid resistance, and mechanical behavior after being heated to 800 degrees Celsius. This is the case in comparison to metakaolin (MK), silica fume (SF), fly ash (FA), and palm oil fuel ash (POFA). By substituting some of the cement in mortar with ground glass, it is feasible to obtain a product with improved performance [12,13]. In order to establish an application for waste glass with varying particle sizes, Lu et al. [14,15] carried out a series of experimental investigations utilising glass cullet and powder in mortar. Purpose of these studies was to develop an application for waste glass. It was discovered that fine glass powder had the potential to reduce the ASR expansion brought on by waste glass aggregate. This resulted in an increase in the material's strength, which was clearly attributable to the pozzolanic effect as well as the ability to fill the microstructure. Recent research has also looked at how using various kinds of waste glass as fine aggregate might change the characteristics of mortar or concrete. Tan et al. [16,17] studied the effects of different colours on the freshness, mechanical, and durability properties as well as alkali-silica reactions of mortars. They proposed that the mechanical properties and flowability were reduced for the glass sand as fine aggregate, but the resistance to chloride ion penetration increased. Additionally, the ASR expansion was promoted for the clear glass sand, but it was reduced with the green and brown glass sand. Due to the fact that colour separation of waste glass was still seen to be one of the technological obstacles that needed to be overcome in order to recycle waste glass, waste glass that contains a variety of colours is more prevalent with transition metals [18]. Research has also been done on specialised kinds of glass. Choi et al. [19] conducted research to determine whether or not recycled heavyweight waste glass might function well as fine aggregate in mortar. Due to the permissible value of fly ash or blast furnace slag, the ASR expansion steadily grew as the glass content went up. This caused the expansion to take place. Wang [20] concentrated on liquid crystal display (LCD) glass sand concrete and discovered that the durability of concrete with 20% glass powder was the best, and was better than that of the control concrete. This was the conclusion he came to after doing research on the topic. In addition to this, a slump loss was discovered in the LCD glass sand concrete, which was in agreement with the findings of Ismail et al. [21]. When there was 10% and 20% glass sand content, respectively, the slump was reduced by 23% and 33%. In addition to the features discussed above, water penetration in mortar or concrete may cause deterioration or certain aesthetic difficulties, which in turn reduces the long-term performance of the building as well as its service life [22,23]. On the other hand, very few researchers have focused their attention on permeability. For instance, Lu et al. [24] investigated the influence of recycled concrete aggregate and waste glass aggregate on the permeability of concrete and discovered that waste glass aggregate concrete had a lower impermeability than recycled concrete aggregate concrete. The permeability of waste glass aggregate concrete was investigated by Bisht et al. [25] at a variety of replacement levels, including 18%, 19%, 20%, 21%, 22%, 23%, and 24%. According to these findings, there was a negative correlation between the amount of glass sand present and the permeability of the material. In addition, research on the impermeability of glass sand concrete has not been sufficiently thorough, despite the fact that permeability one of the main markers for durability of cement-based materials with SCM's. For example, the replacement percentage was not from 0% to 100%, and the reason for the change in permeability was not evident because of the varying gradations of natural sand and glass sand. This was due to the fact that the sand used in the experiment was both natural and glass. An experimental inquiry was carried out with the purpose of analysing the effect that using waste glass as a fine aggregate has on the permeability of the mortar. This article presents the findings of that investigation.

Materials

Cement (C)

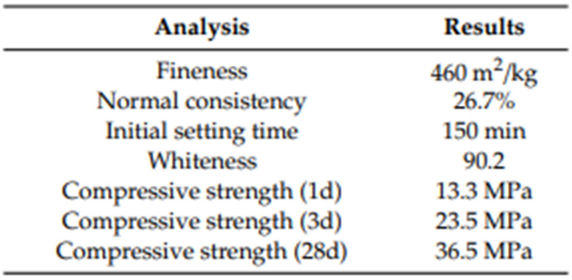
In order to get the desired visual appearance for the mortar, white ordinary Portland cement with a portland weight of 32.5 was employed. The cement's many chemical components are outlined in Table 1, which may be found here. Table 2 outlines the physical and mechanical properties of the cement used in the present research work.

Table 1. Chemical compositions of cement and Metakaolin.



Chemical Composition (%)	Cement	MK
SiO_2	15.31	52 ± 2
Al_2O_3	1.67	45 ± 2
Fe_2O_3	0.28	<0.4
CaO	63.83	<0.4
MgO	6.82	<0.2
SO_3	2.19	-

Table 2. Physical and mechanical properties of Cement.



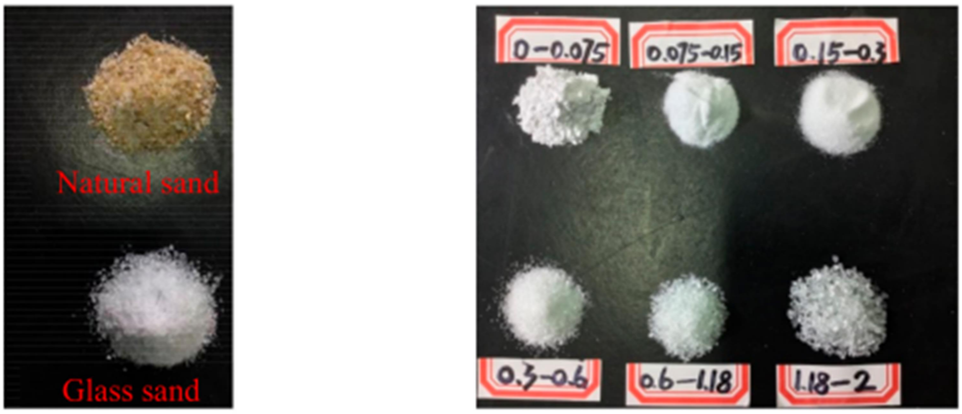
Analysis	Results
Fineness	460 m^2/kg
Normal consistency	26.7%
Initial setting time	150 min
Whiteness	90.2
Compressive strength (1d)	13.3 MPa
Compressive strength (3d)	23.5 MPa
Compressive strength (28d)	36.5 MPa

Metakaolin (MK)

Metakaolin is a kind of pozzolanic substance with large amount of aluminium oxide, and in most cases it performs the role of a suppressor agent in order to reduce the ASR because of Al_2O_3. The color is white, which closely resembles the colour of cement. The average particle size of MK is 10 micrometres, and its chemical compositions are presented in Table 1 along with their respective citations.

Aggregates

As can be seen in Figure 1, natural sand that conforms to the ISO standard and glass sand are both used in the production of fine aggregates. The waste flat glass in China is seen in Figure 2; this kind of glass made up 48.9% of the total quantity of trash glass in China in 2018 [4]. Using a hammer crusher, the flat glass was broken down into fragments that had a size of less than three millimetres. The particles were sieved using specialised gradations ranging from 0 to 2 millimetres, which corresponds to the ISO standard sand gradation. Figure 3 illustrates the aggregate gradation curve for better clarity. A fineness modulus value of 2.1 has been determined for aggregate.



(a) (b)

Figure 1. Sand that conforms to ISO standards as well as glass sand, but with varying particle sizes. (a) natural sand as well as glass sand; (b) waste glass powder composed of particles of varying sizes.

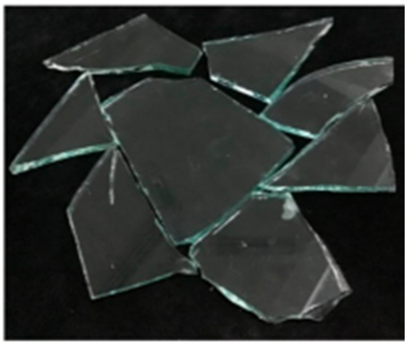


Figure 2. Waste flat glass.

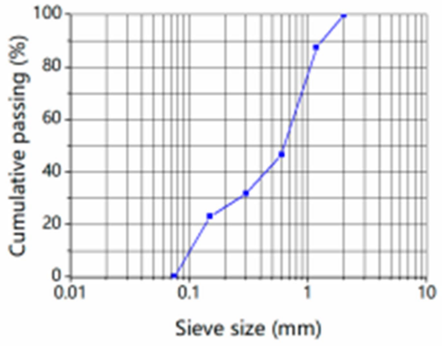
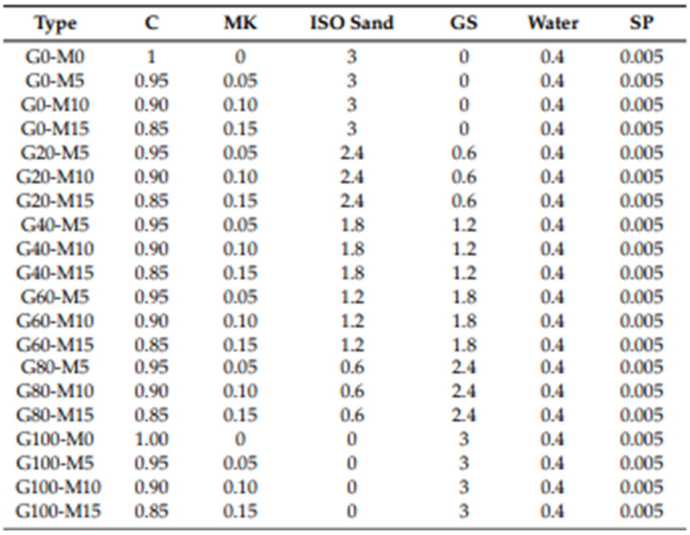


Figure 3. Gradation curve of aggregate.

2.2. Mix Proportions

Glass sand was used in place of natural sand at one of six different weight percentages (0 percent, 20 percent, 40 percent, 60 percent, 80 percent, and 100 percent). The weight of cementations materials (C + MK) was comprised of five percent, ten percent, and fifteen percent MK, respectively. In this particular experiment, the ratio of water to binder, denoted by W/B, was 0.40. The addition of the super plasticizer to the mortar at a rate of about 0.5 percent of the total weight of the cementations ingredients was done so as to increase the workability of the mortar. The specifics of the 20 mix proportions, including the relative weight of cementitious components, are shown in Table 3, which may be seen here. In addition, the ratio of the materials is represented in the table by the figure that does not have a unit next to it.

Table 3. Mix proportions of mortar.

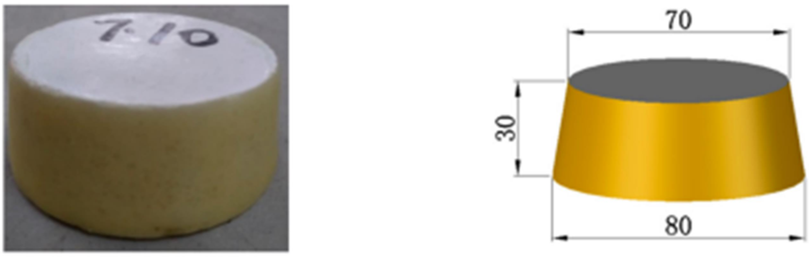


Type	C	MK	ISO Sand	GS	Water	SP
G0-M0	1	0	3	0	0.4	0.005
G0-M5	0.95	0.05	3	0	0.4	0.005
G0-M10	0.90	0.10	3	0	0.4	0.005
G0-M15	0.85	0.15	3	0	0.4	0.005
G20-M5	0.95	0.05	2.4	0.6	0.4	0.005
G20-M10	0.90	0.10	2.4	0.6	0.4	0.005
G20-M15	0.85	0.15	2.4	0.6	0.4	0.005
G40-M5	0.95	0.05	1.8	1.2	0.4	0.005
G40-M10	0.90	0.10	1.8	1.2	0.4	0.005
G40-M15	0.85	0.15	1.8	1.2	0.4	0.005
G60-M5	0.95	0.05	1.2	1.8	0.4	0.005
G60-M10	0.90	0.10	1.2	1.8	0.4	0.005
G60-M15	0.85	0.15	1.2	1.8	0.4	0.005
G80-M5	0.95	0.05	0.6	2.4	0.4	0.005
G80-M10	0.90	0.10	0.6	2.4	0.4	0.005
G80-M15	0.85	0.15	0.6	2.4	0.4	0.005
G100-M0	1.00	0	0	3	0.4	0.005
G100-M5	0.95	0.05	0	3	0.4	0.005
G100-M10	0.90	0.10	0	3	0.4	0.005
G100-M15	0.85	0.15	0	3	0.4	0.005

Note: GS: glass sand; SP: super plasticizer, Waste Glass Powder

Preparation of Specimens

Before the new mortar paste with 20 mix proportions was demoulded, it was cast in a room with a temperature of 20 degrees Celsius plus five degrees and kept there for twenty-four hours. The specimens were kept in a room with a temperature of 20 °C and a humidity of over 90% for 3, 7, 14, and 28 days, respectively. The specimens were in the form of a truncated cone, which can be seen in Figure 4. The height of the specimens was 30 millimeters, and the diameter of the top and lower surfaces was 70 and 80 millimeters, respectively. On one of the specimen's sides, a glue made of rosin and paraffin was applied. At the same time that the mortar paste was being mixed, a test for water permeability, as well as tests for consistency and density, were carried out concurrently.



(a) (b)

Figure 4. Specimen for determining the water's Permeability to pass through.

(a) Specimen size;

(b) Mortar that has been treated with a sealing material.

Experimental Methods

Mortar Consistency Test

A cone and a container make up the bulk of the components that make up a mortar consistency tester. Before beginning the experiment, the point of the cone that had a height of 145 mm, a diameter of 75 mm, and a weight of 300 g was brought into close proximity with the surface of the new paste that was contained inside the conical container that measured 180 mm by 150 mm. After the preparation was complete, the fastener was undone so that the cone could descend without restriction. After allowing the cone to sink for ten seconds in the mortar, the fastener was then closed, and the sinking value was recorded. According to the requirements of the Indian Standard test method for performance on concrete [26]), all procedures were completed within the allotted time of fifteen minutes. The number used to determine the level of consistency was determined to be the average of the two findings. The freshly mixed mortar, which had a high consistency, had a greater degree of workability.

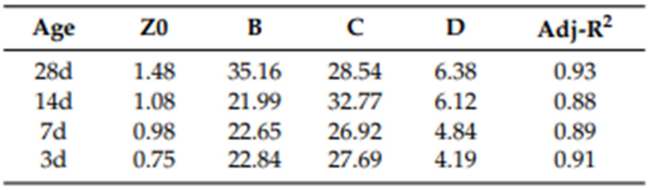
Mortar Density Test

The density test of new mortar was performed to investigate the influence on density that varying amounts of MK and glass sand in the mortar had. For the purpose of loading new mortar, a steel container of one litre was utilised, as required by the Standard [26]. Following that, the container that was freshly filled with mortar was placed on a platform that was vibrated for ten seconds. In the end, the weight of the mortar was used to determine the density, and the value that was obtained by averaging the results of two separate tests was recorded.

Water Permeability Test

Twenty different quantities of the mix were tested at three, seven, fourteen, and twenty-eight days of age, and the results are given in Tables 3 and 4. Based on National standard [26], evaluations were performed on a total of eighty groups, with six specimens being examined within each group.

Table 4. The result of regression analysis.



Age	Z0	B	C	D	Adj-R^2
28d	1.48	35.16	28.54	6.38	0.93
14d	1.08	21.99	32.77	6.12	0.88
7d	0.98	22.65	26.92	4.84	0.89
3d	0.75	22.84	27.69	4.19	0.91

For the purpose of determining the water permeability of the mortar, a mortar permeability tester that had a capacity of six specimens per group was used (as can be seen in Figure 5). After the six samples had been positioned appropriately on the permeability tester, the machine began to progressively raise the water pressure until it reached an initial value of 0.2 MPa. This pressure was then held constant for a period of two hours at 0.2 MPa. In accordance with the predetermined plan, the hydraulic pressure was allowed to gradually increase at a rate of 0.1 MPa per hour until the top surface of the third specimen got soaked in liquid. The impermeability value of this group was determined to be the amount of time it took for the third specimen to get wet.

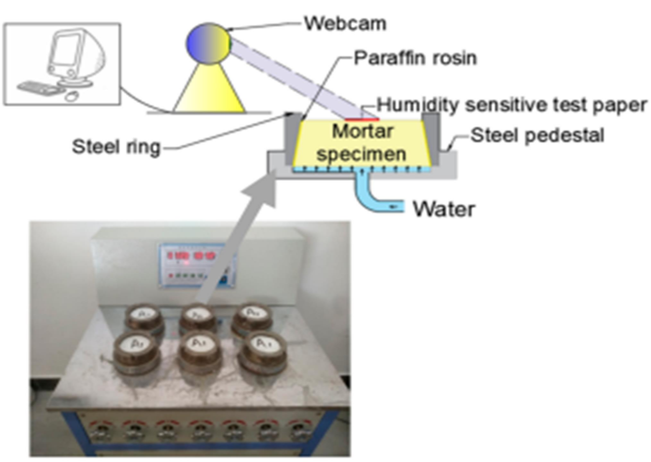


Figure 5. Water Permeability test.

During the period of observation, a novel approach to carrying out this experiment was suggested. As can be seen in Figure 5, one indicator of water seepage was a humidity-sensitive test paper that was affixed to the top surface of the specimen. When the water had fully infiltrated the specimen, the test paper would change color from white to red (as can be seen in Figure 6). In addition, a camera was used in this experiment so that online updates on the status of the test could be seen. As a consequence of this, the camera was able to identify the shift in color that occurred on the test paper, and the data from the test could be retrieved from the computer.

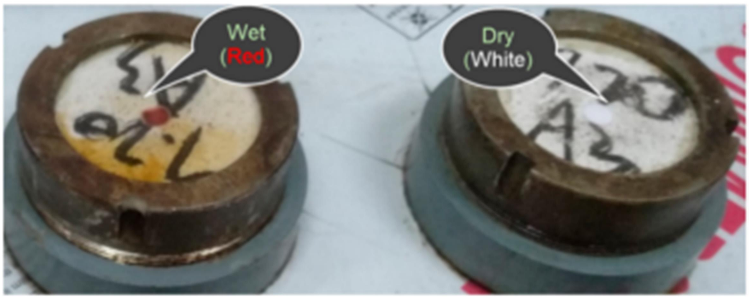


Figure 6. The color comparison of test paper.

3. Results and Discussions

The consistency of freshly mixed mortar that contains varying proportions of MK and glass sand is seen in Figure 7. The consistency became much less thick as the amount of glass sand in the mixture increased. When compared to the mortar that did not include any glass sand, the consistency of the mortar that was combined with 100% glass sand was much less dense, decreasing by up to 55%. This mortar's fluidity and workability were comparable to those of the fresh mortar. According to Tan et al. [16], the fluidity of the new mortar decreased with the rise in the amount of glass sand, which was in line with the findings of the test. On the other hand, Lu et al. [27] and Ling et al. [28] discovered that the incorporation of glass into cement led to an increase in its fluidity. The explanation for this was because the particle size of the glass sand employed in the two experiments was different; the particle size ranged from 0–2 millimetres in this experiment, but in Lu et al.'s experiment, the particle size ranged from bigger to smaller. In comparison to natural sand, the particle size of glass sand had a greater aspect ratio and specific surface area, both of which contributed to an increase in the frictional resistance between particles and a decrease in the amount of free water that was present in mortar. Further that spacing may be attacked by environment component and leads to weakening of concrete.

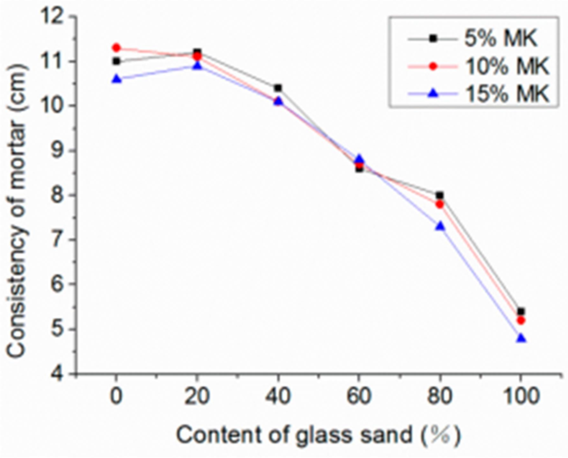


Figure 7. Analysis of the effect that glass sand has on the texture of new mortar, Amount of waste Glass Powder

In addition, concrete that was combined with 5% MK shown a greater uniformity across the board, while mortar that was mixed with 15% MK demonstrated the decreased consistency. It was claimed by Courard et al. [29] that 20% MK caused a reduction in consistency of 25%, however this effect was only seen in regular mortar. The minimal mortar consistency of 4.7 cm was achieved when the content of the waste glass powder and MK were respectively 100% and 15% of the total. In addition, the consistency changed from 5.4 centimeters to 4.7 centimetres in the group that included 100% glass sand as the percentage of MK in the mixture grew from 5% to 15% upto optimization.

The Fresh Density of Mortar

Figure 8 illustrates the difference in density that occurs when new mortar is mixed with glass sand and MK. Regardless of the varied amounts of MK that were used, increasing the amount of glass sand resulted in a lower density. The highest replacement percentage of 100% resulted in a loss in fresh density of 7.9%, while a replacement percentage of 40% resulted in a decrease of 2.7%. Tan observed [16] that mortars containing a variety of colored glass shards as fine aggregates had a lower density. Ismail et al. [21] discovered that when glass sand was used instead of the natural fine aggregate in concrete, the fresh density of the concrete was lower. Irregular dimension glass powder is answer for this invention [30]. In these experiments, the particle sizes of glass aggregates were varied, but they were still able to decrease the density of the mortar, with the exception of some specialized types of glass. Because of the way the three curves are positioned in respect to one another, it is possible to deduce that there was no clear connection between mortar density and MK content. To investigate the nature of the connection that exists between the fresh density of mortar and the amount of glass sand present, a regression analysis was carried out. The following is an outline of a suggested model:

$$Z = a \times x + b \qquad (1)$$

When x is the proportion of glass sand, z represents the fresh density of mortar, and a and b are the coefficients produced by doing a regression analysis on the data. The results of the study show that the value of an is 2242.73, and the value of b is -1.79. The fact that this model has a correlation coefficient R2 of 0.94 suggests that the outcomes predicted by the numerical model correspond well to those predicted by the actual test.

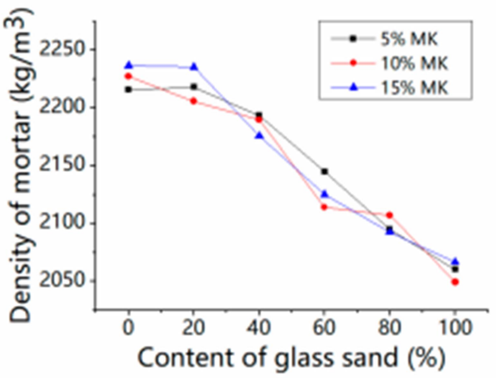
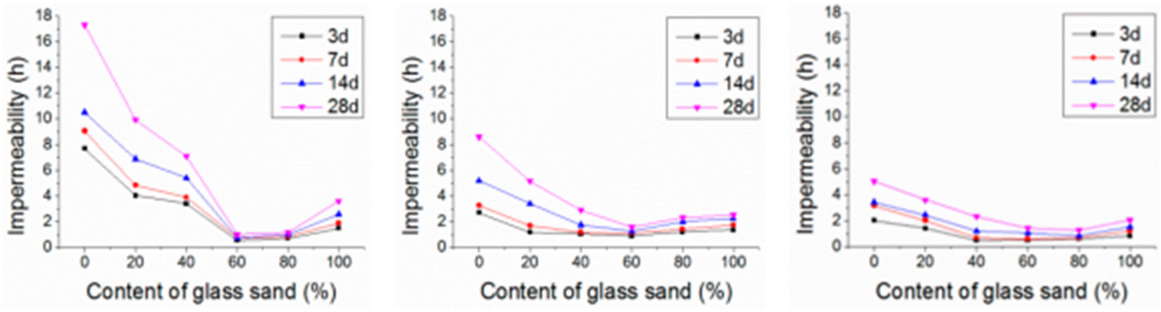


Figure 8. Impact on the cohesiveness of the newly mixed mortar.

Water Permeability of the Mortar

Figure 90shows the impermeability of the mortar with the glass and MK, respectively. The impermeability of the mortar drastically dropped with the quantity of the glass sand, but then it grew somewhat after that. The impermeability of the mortar that was made with 5%, 10%, and 15% of MK at the age of 28 days achieved its minimal value with glass content between 60% and 80%, and in comparison to the mortar that was made with 100% natural sand, it was lowered by 94%, 83%, and 73%, respectively. Bisht et al. [25] reported the results of an experiment with concrete that was quite similar to this one, although the percentage of glass sand in the mix only varied from 18% to 24%. Because the glass sand was more angular than the natural sand, this might be the reason why there were more holes in the mortar made with shuffling of glass sand. These pores included fissures and gaps between the glass and the cement mortar. [25,30] Accordingly the prediction that the glass particles were more porous than the natural sand. In addition, the water absorption coefficient changed depending on the quantity of glass sand replacement. This Coefficient of this describes the propensity of a porous material to both absorb and transfer water through capillarity. The findings from the SEM pictures, which can be seen in Figure 10 lent more credence to this theory. In comparison to the natural sand found in the G0-M15 group, the glass sand found in the G60-M5 and G100-M15 groups had a surface that was more uniformly smooth and included a greater number of edges and angles. In addition, several abnormalities in hole manifested themselves in the interface zone (ITZ) between the glass powder and the paste. In all the glass particle mortar and the concrete, similar results were discovered.



(a) (b) (c)

Figure 9. Impermeability that varies depending on the amount of glass sand present. (a) MK at 5%; (b) MK at 10%; (c) 15% MK.

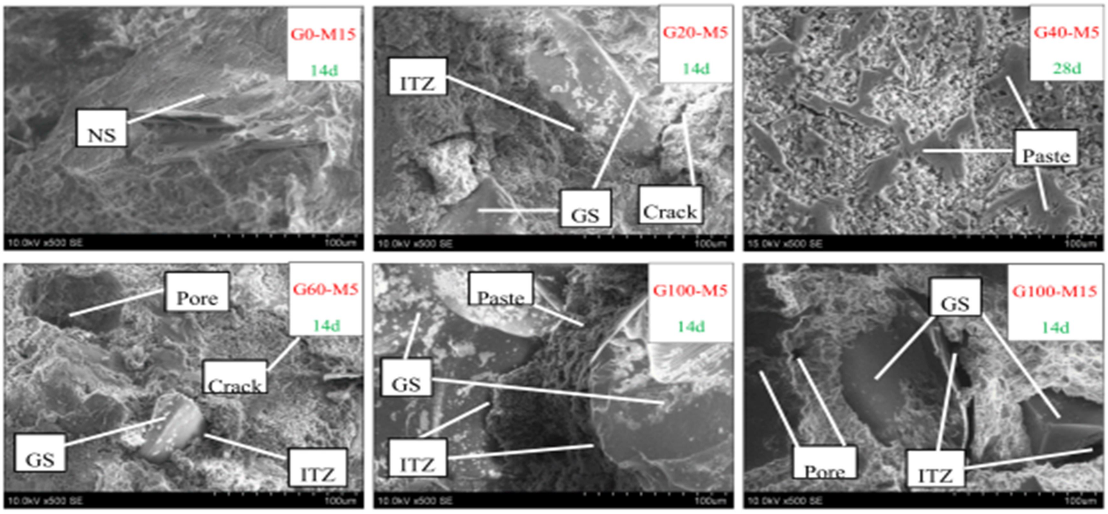


Figure 10. SEM images of mortar (magnification = 500, 14d: 14 days, 28d: 28 days).

In general, the impermeability of the cement dropped and then slightly rose, with a range in the 28d group that went anywhere from 12% to 27%. According to Penacho et al. [30], the water retentively of glass sand mortar was better than that of usual mortar because of specific surface areas for to the cement hydration, which validated the claim. It was reported by Ling et al. [28] that the impermeability of mortar is slowly increased when the content of the glass sand was over 60%, and even increased with a percentage of 100%. Accordingly correlation is directly related to the fact that the permeable voids of the mortar are increased as the percentage of glass in the mortar increased. However, the percentage of permeable voids decreased when the percentage of glass sand in the mortar increased. In this experiment, we looked at the microstructures of mortars made with varying quantities of the various mix ingredients. As can be seen in Figure 11, the mortar that was part of group G60-M5 had a more porous microstructure than the mortars in the other groups. Meanwhile, there were huge holes in the G60-M5 group by GeeTable :3). The presence of porous microstructures leads to a reduction in the impermeability of mortar containing between 60 and 80 percent glass sand.

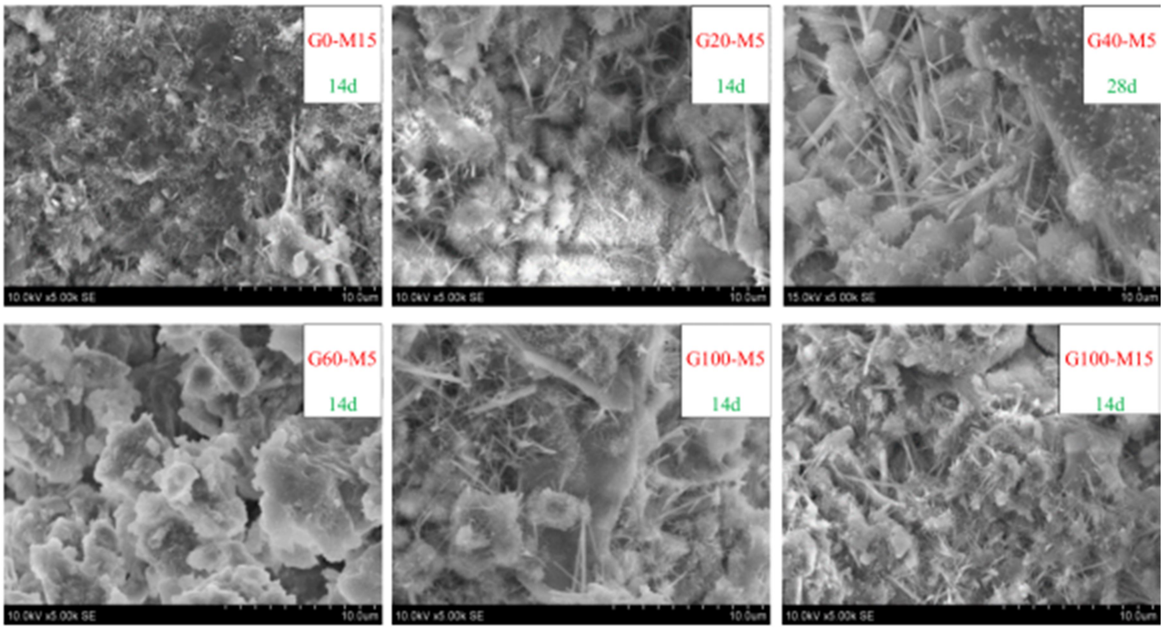


Figure 11. SEM images of mortar (magnification = 5000, 14d: 14days, 28d: 28 days).

In addition, in contrast to the fine aggregate that was used in prior research [25,36], where size of the glass sand employed in this experiment covers the range of 0 to 2 millimetres. Here possibilities of substituents by use of waste glass powder may be made from glass particles with a specific dimensions a diameter ranging from 38 to 300 mm. A little amount of pozzolanic activity predicted when the particle size of the waste powder glass was more than 1 millimetre as compared with this investigation, 31.8% of the total was comprised of glass sand that had particles no bigger than 300 micrometres. Particularly when the amount was more than 60%, the features of the glass sand led to superior pore structures in the mortar[32]. In contrast, the form of glass sand was more irregular when compared to the shape of natural sand (as can be seen in Figure 11), and the particle tip of glass sand was able to fill big apertures. Prior to the addition of 60% of the substance, there were less big holes, and as a result, the filling effect was not immediately noticeable. When the percentage of glass sand reached sixty percent, the number of big pores began to rise, and the effect was made more noticeable. Therefore, there were the most pores and the impermeability was at its worst when it was at 60%.

Conclusions

In this particular investigation, waste glass was used in place of natural sand in the role of fine aggregate. In the meanwhile, MK was employed as the substituent rather of the white cement with a substitution rate of 5%, 10%, and 15%, which lowers the alkali-silica reaction. We investigated that how the presence of MK and glass affected the characteristics of the mortar. The following are some of the inferences that may be drawn: The consistency of the mortar became less thick as the amount of glass and MK added to it increased. The presence of glass contributed to an acceleration of the downward trend. At its thickest, mortar made with 100% glass sand had a consistency that was 55% less consistent than normal. The replacement rate of 40% resulted in a 2.7% drop in the density of new mortar, whereas 100%

resulted in a 7.9% decrease[33]. In order to accurately forecast the consistency, there is a regression association (with an adjusted R2 value of 0.91) between the density and the consistency. Because glass powder has a dimensional surface, electron micrographs indicated that there was a fracture between the matrix and the WGP. Furthermore, larger pore structures were discovered in mortar that included 60% glass powder, which led to an increase in the mortar's water permeability [31]. An impermeability regression model that can predict the impermeability of glass sand mortar altering with glass sand content, MK content, and age was constructed. The model can also forecast the impermeability of the mortar over time. Because adding glass sand to mortar may considerably boost its permeability, this kind of mortar can be utilised as a pervious material; the ideal amount of glass powder to mortar is anywhere between 60 and 80 percent. Our earlier studies on polypylene fibre and cow dung ash 32 explains the role of fibre and spherical particle

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