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Analysis of Fine Glass Waste Addition as a Filler Material for Sand Substitution on the Properties of Mortar Products

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Abstract

Inorganic glass waste can replace sand in mortar production due to its SiO_2 content being greater than 70%. This study aims to analyze the increase in mortal product agility due to the substitution of sand and reducing environmental pollution. The fine glass waste used is restrained on 80 and 120 mesh sieves. The fine glass waste substitution variations are 0, 10, 20, 30, 40, and 50% of the sand weight. The results show that fine glass waste could be used as a material for sand substitution because of the content of SiO2 of 73.8%. The results from XRD indicate that the phase of fine waste glass is amorphous. The mortar was printed with a 5x5x5 cm cube mold, and it was soaked for 7, 14, and 21 days. Based on the results, the compressive strength with a high value of 13.58 MPa at 20% fine glass waste substitution and 120 mesh. The density of 2.8±0.8 g/cm^3, porosity 4.40±0.001%, and absorption 2.83±0,0009%. The compressive strengths, density, porosity, absorption, XRF and XRD characterization were evaluated. The results showed that the SiO_2 compound in waste glass with the right composition of 20% could significantly increase the compressive strength. Phase formation of Calcite ($CaCO_3$), Quartz (SiO_2), and Portlandite ($Ca(OH)_2$) was formed from the results of XRF characterization

Keywords: *fine glass waste; sand; filler; mortar*

1. Introduction

Mortar is a mixture of cement, sand, and water. Sand is the most widely used as a raw material in mortar production, approximately 60-70% of the total. The more sand as aggregate, the more the amount needed, so the availability of sand in nature decreases. It is necessary to research alternative raw materials to replace the sand. One of the wastes that can be used as a substitute for sand in mortar is glass waste. Glass waste is an abundant inorganic waste, reaching 0.7 million tons per year in Indonesia. Most of it comes from bottles, building glass waste, and kitchen glass. The main compound contains more than 70% SiO_2. Glass waste can be used because it contains SiO_2, available in large quantities, and reduces environmental pollution. (Ramadani, 2018; Choi et al., 2018).

Several studies have carried out the addition of glass waste for mortar manufacture. For example, Choi et al. (2018) reported using glass waste to substitute sand in mortar. The glass waste used has passed a 5 mm sieve and a density of 3.0 g/cm^3. The results show that the burning loss decreases when the substitution ratio of waste glass increases. However, the expansion of mortar by Alkali-Silica Reaction (ASR) gradually increases with the increasing substitution ratio of waste glass. However, waste glass is suitable for fine aggregate in mortar specimens (Choi et al., 2018).

Furthermore, another study by Bentchikou et al. (2017) used fine glass waste with variations of 10%, 25%, 35%, 50%, 75%, and 100% with immersion times of 7, 28, and 90 days. The glass waste used has a fineness level of 3.83 cm^2/gram and a density of 2.49 g/cm^3. The substitution variation of 35% and 10% on day 28 was optimal in terms of the mechanical strength of the mortar.

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Table 1. The composition of production mortar

Glass substitution (wt.%)	Cement (g)	Sand (g)	Glass waste substitution (g)	Wate r (ml)
0	500	2.500	0	300
10	500	2.250	250	300
20	500	2.000	500	300
30	500	1.750	750	300
40	500	1.500	1.000	300
50	500	1.250	1.250	300

When fine glass waste is used as a filler with a smaller particle size and combined with the pozzolanic reaction, it is possible to get a better mortar. Furthermore, adding 10% and 20% substituted fine glass waste used in mortar as a substitute for natural aggregate and cement, respectively, has good compressive strength. Therefore, the use of glass waste can reduce the use of cement, which causes environmental impacts (Letelier et al., 2019).

2. Materials and Methods

2.1 Materials

The materials used are fine glass waste, sand, PCC cement (Portland Composite Cement), and water. The raw material in mortar production, such as cement, sand, fine glass waste, and water, with the composition, were presented in Table 1.

2.2 Mortar Preparation and Production

The preparation of this study followed the research of Amin and Suharto, 2017. First, the glass waste was pulverized using Ball Milling for five h to obtain fine glass waste. Then, the fine glass waste was sieved using 60, 80, 100, and 120 mesh sieves (SNI. 03-1968-1990). Next, fine glass waste, sand, cement, and water are stirred in a mixer for 20-30 min until it becomes a cement mixture. Furthermore, it was molded with a 5×5×5 cm cube mold until it became a mortar. The mortar dried at room temperature for 24 h. Finally, the mortar was removed from the mold. Mortar soaked in water for 7, 14, and 21 days (SNI. 03-6825-2002).

2.3 Characterization of mortar

Mortars were characterized by X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF), and physical tests such as porosity, absorption, density, and compressive strength .

3. Results and Discussion

The results of X-Ray Fluorescence (XRF) characterization on the sand and fine glass waste can be seen in Table 2. Table 2 shows that sand has the highest SiO_2 compound content of 64.8%, while fine glass waste is 73.8%. Glass waste can be used as a substitute for sand because it contains a lot of SiO_2 compounds. SiO_2 compounds can increase the compressive strength significantly (Walczak et al., 2015). In addition, the use of glass waste as a substitute for sand can reduce unused glass waste (Rahim et al., 2015).

Table 2. The results of XRF characterization on the sand and fine glass waste

Compound	Sand (wt.%)	Fine glass waste (wt.%)
SiO_2	64.8	73.8
CaO	6.2	16.8
Fe_2O_3	11.0	3.4
MgO	0.2	2.3
Al_2O_3	7.4	2.0
P_2O_5	1.3	1.0
K_2O	1.7	0.3
TiO_2	4.4	0.2
MnO	0.2	0.1

The XRF results obtained for the waste glass samples are comparable with a standard pozzolana in which (SiO_2 + Al_2O_3 + Fe_2O_3)'s minimum requirement is 70%. Therefore, glass powder samples can be considered in par to pozzolanic behavior in cement systems.

The diffractogram of sand and fine glass waste is shown in Figure 1. Figure 1 shows the characteristics of the sand are Quartz (Joni et al., 2019). The phase formed in the XRD characterization results is in accordance with the XRF results, containing many SiO_2 elements.

Figure 1 shows that the characteristics of fine glass waste are not structured (amorphous). This is indicated by the absence of diffraction peaks formed (Olofinnade et al., 2015). The amorphous formation is caused when SiO_2 glass is made by heating at high temperatures.

The results on the physical properties of sand can be seen in Table 3. Based on Table 3. it can be seen that the water content test determines the difference in weight between the materials before and after drying. The water content results are (1±0.002)%. Based on ASTM D-2216 (1999), the sand moisture content test qualified because it has a moisture content of less than 10%. If it is more than 10%, it will cause a decrease in the mechanical strength of the mortar because the sand will absorb too much water.

The table also shows that mud content testing to determine the percentage of silt contained in the sand. The silt content test in the sand is obtained at (4.5±0.001)%. This sand qualified, which is less than 5% based on SNI S-04-1989-F. Excessive mud content will interfere with the adhesion between the surface of

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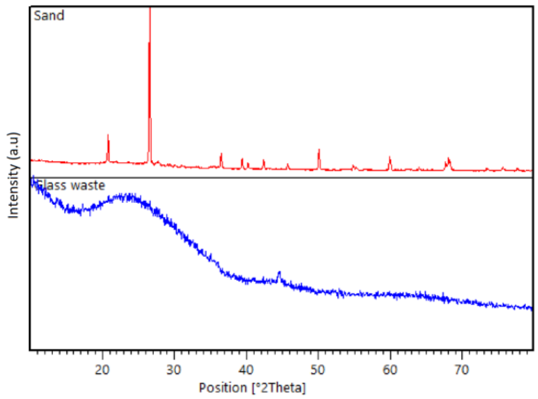

Figure 1. The diffractogram of sand and fine glass waste

the sand particles and cement paste, thereby reducing the compressive strength of the mortar.

Based on the gradation test of the sand obtained size of 2.37±0.01. The results requirements as fine sand based on SNI. 03-1968-1990, because it has a fine particle modulus between 2.20 to 2.60. In general, sand is grouped into three levels of fineness, fine sand of 2.20-2.60, medium sand of 2.60-2.90, and coarse sand of 2.90-2.60. Overall, the sand material used in this study has requirements as a substitute for sand in the manufacture of mortar.

3.1 Mortar Physical Test Results on the Composition of Refined Glass Waste

3.1.1 Compressive Strength Results

Compressive strength testing aims to determine the magnitude of the load per unit area. However, it causes the test object to crumble when loaded with a certain compressive force by the machine. The manufacture of this mortar uses fine glass with particle sizes of 80 and 120 mesh as a substitute for sand with the mortar treatment soaked for 7, 14, and 21 days. Then the compressive strength test is carried out using the UTM machine. Based on the test results, the compressive strength of mortar with variations in substitution of fine glass waste soaked for 7, 14, and 21 days can be seen in Figures 2.

The lowest compressive strength results were obtained from the substitution of 20% fine glass waste by immersion for seven (7) days on an 80 mesh molecular sieve. The compressive strength of mortar is 8.98 MPa. The optimum compressive strength was obtained by substituting 20% fine glass waste by immersion for 21 days on a 120 mesh molecular sieve. The compressive strength of mortar is 13.58 MPa. This shows that the longer the mortar is soaked, the better the compressive strength obtained. Due to the C-S-H reaction (Calcium Silicate Hydrate) will be perfectly hydrated in the air (Walczak et al., 2015).

Table 3. Physical properties of sand

Test	Result	Standard	Information
Water content	(1±0.002)%	≤10%	Qualify (ASTM D-2216)
Mud level	(4.5±0.001)%	≤5%	Qualify (SNI S-04-1989-F)
Gradation	2.37±0.01	2.20-2.60	Qualify (SNI 03-1968-1990)

Refined glass waste as a substitute for sand can affect the compressive strength of mortar. This is due to SiO_2 content in fine glass waste functions as a filler in making mortar and has a maximum percentage of sand substitution. However, the production of mortar using raw materials consisting of sand, cement, and water still causes the air voids to be filled with water during the immersion period. This air cavity is covered with fine glass waste to increase the compressive strength of the mortar (Jesus et al., 2019).

However, the substitution of fine glass waste with the right substitution can increase the compressive strength at a maximum substitution variation of 20%. This happens because the addition of fine glass has a maximum limit. The addition of excessive fine glass waste will decrease the compressive strength value and the cement's decreased ability to bind the materials contained in the mortar because it is excessive. The SiO_2 content produced by the substitution of fine glass exceeds 20%. When substitution variations of 30 to 50% were done, the SiO_2 content increased. The SiO_2 content in the mortar decreases the compressive strength. Compressive strength decrease was caused by the mortar having excessive shafts or pores. Substitutions of up to 20% have similar results to traditional mortal mixtures.

Meanwhile, the substitution of 30% causes a dilution effect that negatively impacts the insufficient amount of $CaCO_3$ that remains to react with silica from glass waste. This causes the mechanical properties to decrease proportionally. (Hambali et al., 2013).

The fine glass particle size of 120 mesh has a higher compressive strength value than the particle size of 80 mesh. This is because smaller particle sizes can fill the pores of the sand more. Therefore, the mortar will become more compact, and the compressive strength value will be higher than the larger particle size.

3.1.2 Density Results

Density testing aims to determine the ratio between the density of a material with the density of water with the same volume. Figure 3 shows the mortar density with variations in substitution of fine glass waste

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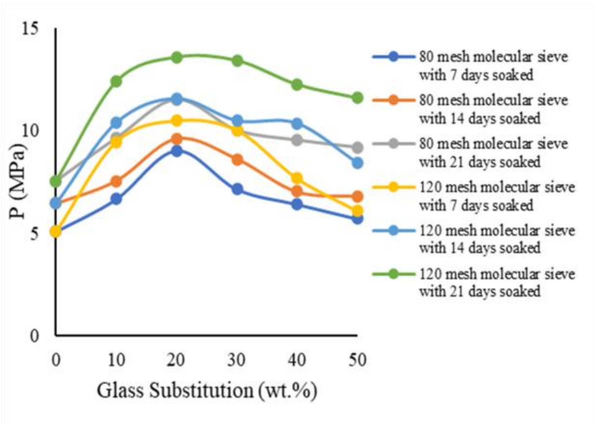

Figure 2. The compressive strength of mortar with variations in substitution of fine glass waste soaked for 7, 14, and 21 days

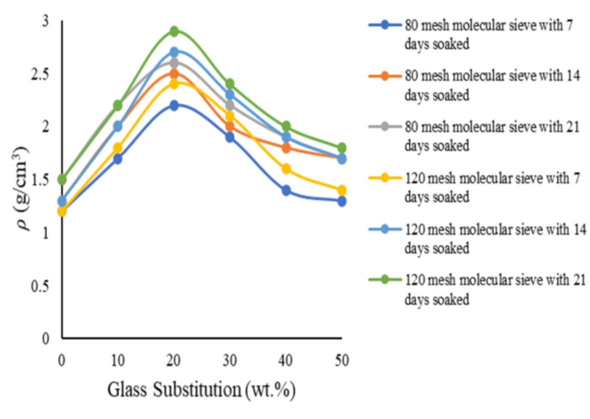

Figure 3. The density of mortar with variations in substitution of fine glass waste soaked for 7, 14, and 21 days

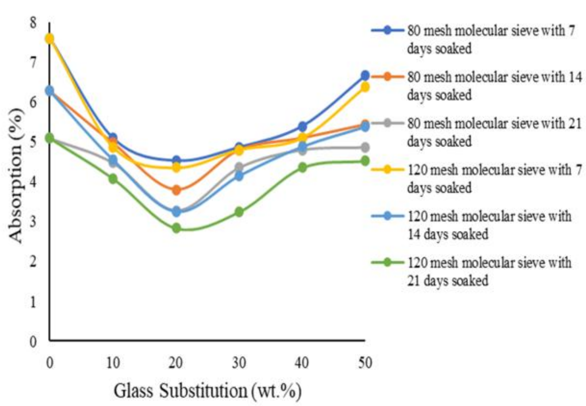

Figure 4. The absorption of mortar with variations in substitution of fine glass waste soaked for 7, 14, and 21 days

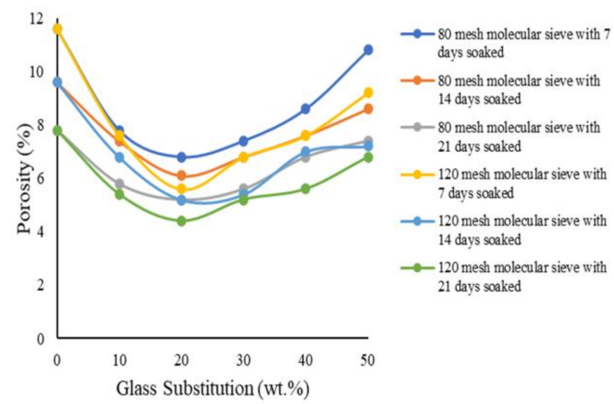

Figure 5. The porosity of mortar with variations in substitution of fine glass waste soaked for 7, 14, and 21 days

soaked for 7, 14, and 21 days. The optimum density was obtained by substituting 20% fine glass waste by immersion for 21 days on a 120 mesh molecular sieve. The density of mortar is 2.8±0.8 g/cm^3.

Based on Figure 3, the finer the glass waste used in the mortar mixture, the higher the density produced. This is because sand, cement, fine glass waste, and water are solid, so they are perfectly hydrated with water (Tamanna et al., 2013). The higher the compressive strength of mortar caused, the higher the density value (Jesus et al., 2019). For example, the density value of mortar soaked for 21 days was higher than that of mortar soaked for 7 and 14 days, with a 20% fine glass waste substitution variation. Furthermore, using a particle size of 120 mesh, the obtained density is higher than 80 mesh. This is because the smaller the particle size, the higher the density level, and the smaller the pores.

Glass powder particle size and morphology affect the workability of mortar. Finer glass powder contributes to increased workability by reducing friction between the particles.

3.1.3 Absorption Results

Absorption is a large percentage of air absorption due to air spaces in the mortar. Figure 4 shows the absorption of mortar with variations in the substitution of fine glass waste soaked for 7, 14, and 21 days. The optimum absorption was obtained from the substitution of 20% fine glass waste by immersion for 21 days on a 120-mesh molecular sieve. The absorption is 2.83±0.0009%.

High absorption causes low compressive strength and density, and vice versa. This is because the pores in the mortar are covered by fine glass. The absorption

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Table 4. The results of XRF characterization of mortar

Compounds	Glass substitution (wt.%)			
	80 mesh molecular sieve with 20%	**80 mesh molecular sieve with 50%**	**120 mesh molecular sieve with 20%**	**120 mesh molecular sieve with 50%**
CaO	68.3	62.1	55.2	42.3
SiO_2	19.8	23.4	28.7	37.4
Fe_2O_3	6.0	8.0	8.9	11.7
Al_2O_3	2.8	2.5	2.5	2.4
TiO_2	1.5	2.1	2.8	3.8
SO_3	0.6	0.5	0.4	0.3
MgO	0.6	0.8	0.8	1.2
K_2O	0.2	0.2	0.3	0.3
SrO	0.1	0.1	0	0.1
MnO	0	0.1	0.1	0.1

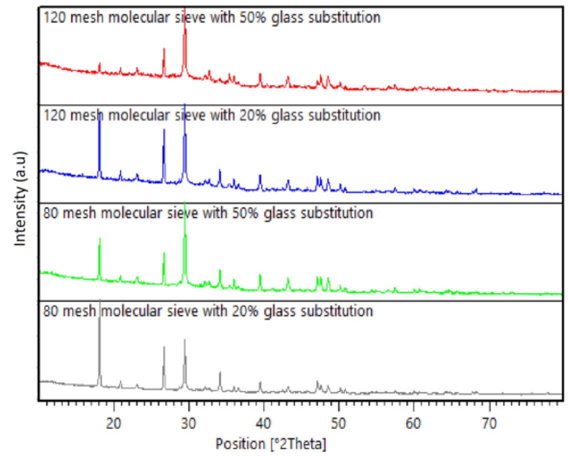

Figure 6. The diffractogram of mortar with 80 and 120 molecular sieves with 20 and 50 % glass substitution

value increases when the percentage of addition of fine glass substitution in the sand ranges from 30-50.

The absorption value on the 120 mesh molecular sieve is better than the 80 mesh size. This is because finer particle size will be easier to cover the air cavities in the mortar. Therefore, the mortar density can be increased. The mortar density can reduce the absorption value so that the density value can increase (Jesus et al., 2019).

3.1.4 Porosity Results

Porosity is the percentage of the pores' size in the mortar. Figure 5 shows the porosity of mortar with variations in substitution of fine glass waste soaked for 7, 14, and 21 days. The optimum porosity was obtained by substituting 20% fine glass waste by immersion for 21 days on a 120 mesh molecular sieve. The porosity is 4.4±0.001%.

The fine glass waste serves as a filler and can reduce the porosity because the pores in the mortar are filled. The porosity value of 30 to 50% is still better than without fine glass waste addition or 0%. The decrease in the porosity value is caused by too much SiO_2 content in the glass and sand, causing the cement's ability to bond sand and glass to decrease. The higher the porosity values, the lower the compressive strength and density values. However, it is directly proportional to the magnitude of the absorption value (Jesus et al., 2019).

3.1.5 X-Ray Fluorescence (XRF) Characterization Results of Mortar

The results of XRF characterization on mortar can be seen in Table 4. XRF results show that mortar has the highest compound content of CaO at 80 mesh molecular sieve with a 20% substitution variation of 68.3%. In contrast, the 50% substitution variation decreases to 62.1%, with a mesh molecular sieve of 120 mesh. However, the SiO_2 content increased with molecular mesh sieve and glass substitution variations.

The greater the substitution of fine glass waste put into the mortar mixture, the more the amount of SiO_2 compounds while the CaO decreases. This is because the refined glass waste contains a lot of SiO_2 of 73.8%. The reduction in CaO was due to being in the glass only 16.8%. Therefore, glass should be limited to making mortar so that SiO_2 in the mortar is adequately supplied. If it is excessive, it will reduce the ability of the cement to bind the mortar (Wibowo., 2017).

3.1.6 X-Ray Diffraction (XRD) Characterization Results of Mortar

XRD was used to identify the composition elements of each phase in the mortars based on the mineralogical identification. Thus, X-ray diffraction (XRD) characterization results allow a qualitative understanding of mortar type and function.

Figure 6 shows the diffractogram of mortar with 80 and 120 molecular sieves with 20 and 50 % glass substitution. On these substitutions, the results show that the phases that dominate the diffraction peaks are Calcite ($CaCO_3$), Quartz (SiO_2), and Portlandite ($Ca(OH)_2$). These are the phases of compounds that greatly influence the strength of the compressive strength, density, absorption, and porosity.

In the 20% substitution variation, the phase is dominated by the Calcite phase ($CaCO_3$) derived from CaO, which reacts with CO_2, followed by the Quartz phase (SiO_2) (Huseien et al., 2019). In the 50% substitution variation, the Quartz (SiO_2) phase increased. This was due to the increase in the substitution of fine glass waste. Meanwhile, the Calcite ($CaCO_3$) phase decreases because, based on XRF data, CaO has decreased while SiO_2 has increased.

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The peak height for each variation of 20% and 50% is different. At 20% substitution of glass waste, it was found that 2θ of 29.4175º and 29.4092 indicated the Calcite phase ($CaCO_3$). Meanwhile, 50% substitution 2θ of 18.1027º and 29.4152º indicated the peak of the Portlandite ($Ca(OH)_2$) phase. This phase is formed because there is much SiO_2 content. Excessive SiO_2 content will bind to free CaO and form $Ca(OH)_2$. ($Ca(OH)_2$) comes from CaO, which reacts with water and forms a bond with Calcium Silicate Hydrate (CSH), the most important compound in cement formation (Tamanna et al., 2013).

4. Conclusions

Glass waste can be used as a substitute for sand because it contains SiO_2 compounds of 73.8%. SiO_2 compounds can increase the compressive strength significantly but with the right composition by 20%. The optimal results were obtained by both adding 20% fine glass waste substitution variation and soaking for 21 days with a molecular sieve of 120 mesh, for compressive strength of 13.58 MPa, the density of 2.8±0.8 g/cm^3, absorption of 2.83±0.0009 %, and porosity of 4.40±0.001 %. In this study, adding fine glass waste to mortar will result in the formation of phases such as Calcite ($CaCO_3$), Quartz (SiO_2), and Portlandite ($Ca(OH)_2$). These phases are needed in the cement hydration process.

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Authors' contributions

Suharto (S), Muhammad Amin (MA), Muhammad Al Muttaqii (MAM) were the main contributors. S and MA tested the samples and interpreted data. MAM collected the data, other information and drafted the article. Roniyus Marjunus (RM), Nuzullia Fitri (NF), Suhartono (SH) are member contributors. RM, NF, SH conducted major reviews, edits and added the analysis.

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