Mechanical Properties of Concrete with Recycled Bottle Glass Powder Substitute

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Received 11 March 2024; received in revised form 25 April 2024; accepted 26 April 2024

Abstract

Concrete is a material that is widely used in the construction of structural buildings. One of the influential factors for obtaining high quality concrete is the aggregate gradation. If the aggregate gradation has a small size and varies, it can reduce the porosity of the concrete so that the concrete becomes denser which makes the quality of the concrete high. In order to use aggregates with fine gradations, this study proposes glass powder derived from glass bottle waste as a partial replacement for fine aggregates. The glass powder used is in the sizes about 0.150 mm - 0.075 mm. Then, the maximum size of 15 mm for the coarse aggregate and the fine aggregate with the gradation of zone 4 (fine sand) were used for the concrete mix. The purpose of this study is to investigate the mechanical properties of concrete i.e. the compressive and split tensile strength of concrete with glass powder as a partial substitution of fine aggregates with a percentage of 10%, 15%, and 20% at a concrete age of 28 days. This study uses the testing method that refers to ASTM standard. From the test results, it was found that the compressive strength of concrete with a variation of 20% glass powder (GPC 20%) increased by 11.32% compared to the compressive strength of normal concrete (NC). For the split tensile strength, the concrete with a 20% glass powder variation (GPC 20%) increased by 15% compared to the split tensile strength of normal concrete (NC). The results showed that the use of glass powder as a partial replacement for fine aggregate in this study was reasonably good to improve the mechanical properties of concrete. Furthermore, as a concern for the environment, it can reduce the environmental impact caused by waste materials of glass bottles.

Keywords: concrete, glass powder, compressive strength, split tensile strength, mechanical properties

1. Introduction

Demand for concrete as a construction material will increase along with infrastructure development. As is known, concrete is a natural resource which, if used continuously, will run out and can damage the environment. This dilemma inspired experts to create environmentally friendly concrete. Creations to obtain concrete with environmentally friendly forming materials are carried out by using waste materials such as replacing cement as a binder, either in whole or in part from cement, and replacing other concrete materials such as fine aggregate. One way to completely replace cement as a binder is to use waste material in the form of fly ash to produce environmentally friendly Geopolymer concrete [1] which can reduce CO_2 emissions by 80%. Replacing some of the functions of cement is also often done with refined waste cementitious materials, one of which is glass powder [2-6]. Meanwhile, replacing some of the fine aggregate or as concrete filler is carried out using materials like rice husk ash [7], volcanic ash [8] or cold lava [9] and waste glass powder [10-11].

Replacing some of the fine aggregate with glass waste powder is one way of using glass bottle waste which is a problem

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in recycling. Glass bottle waste is included in the glass waste that we often encounter in our environment, most of the glass bottle waste is directly dumped into open land or carelessly, this of course will pollute the environment considering that glass is a material that cannot be recycled naturally by nature. Based on the National Waste Management Information System (SIPSN) Ministry of Environment and Forestry of the Republic of Indonesia, the amount of waste in 2022 is 19,137,821.53 tons. Waste that is not managed 22.91% of the total amount of waste. The amount of glass type waste itself is 2.1% of the total waste [12]. This is a significant amount and is of particular concern for the sustainable management of waste glass.

Several reports from previous research have been made regarding the substitution of fine aggregate with recycle glass powder. It has been reported the optimal amount of glass powder as partially substitute of fine aggregate in concrete is 15% [10]. For the glass powder that was investigated as a partial substituted alternative for cement, the results state that the optimum percentage of glass powder as a substitute for cement in concrete is 20% [3]. Furthermore, concerning the effect of variations in coarse aggregate grain size [13], based on the available literature stated that the maximum grain size of 15 mm is best used to obtain high quality concrete.

Based on the previous study that available in the literature, this study uses a percentage of 10%, 15% and 20% of recycled bottle glass powder as partial replacement for fine aggregate. This study uses the smallest gradation of fine aggregate size (gradation no.4) and a maximum coarse aggregate size of 15 mm. The glass powder used is in the form of glass powder gradations retained on the mesh No. 100 – No. 200 or about 0.150 mm - 0.075 mm. Since to obtain pozzolanic properties, glass powder with very fine grains is required. The objective of this study is to investigate the mechanical properties of concrete using recycled bottle glass powder as a partial replacement for fine aggregate with a percentage of 10%, 15%, and 20% at a concrete age of 28 days. The mechanical properties of concrete that is studied in term of the compressive strength and the split tensile strength of concrete. Furthermore, this study is expected to contribute to environmental concerns through using recycled glass bottle waste as partial substitution of fine aggregate in concrete.

2. Material and Method

The mechanical properties of concrete such as the compressive strength and the split tensile strength of the concrete are investigated at age of 28 days. The percentage of use of recycled bottle glass powder as a partial replacement for fine aggregate is varied by 10%, 15%, and 20%. Then, the performance of the mechanical properties of glass powder concrete compared to the normal concrete. All specimens are treated with immersion curing before tested in compressive strength [14] and split tensile strength [15]. The study methodology is shown in Fig. 1.

The main materials for normal concrete (NC) in this study are cement, water, coarse aggregates, and fine aggregates. Meanwhile, for glass powder concrete (GPC), there is additional glass powder as a partial replacement for the fine aggregate. A brief explanation of the main materials used is as follows [16-18], the cement used as a binder for the concrete mixture is Portland Composite Cement (PCC) Type I, the coarse aggregate uses crushed stone with sizes ranging between 4.75 mm and 15 mm with Fineness Modulus (FM) = 6.68% (Fig. 2), fine aggregate uses sand that passes a 2.36 mm sieve with sieve gradation of zone 4 (fine sand) where Fineness Modulus (FM) = 2.17% (Fig. 3). The coarse and fine aggregate are tested for specific gravity and absorption, mud levels, aggregate gradation, and aggregate moisture. The recycled glass powder bottles used passed sieve number 200 with sizes ranging between 0.075 mm and 0.150 mm (Fig. 4). The mix design of normal concrete and glass powder concrete can be seen in Table 1. The concrete specimens used in this study are cylinders with a diameter of $Ø$ = 150 mm and height of h = 300 mm (Fig. 5 and Fig. 6). The compressive strength and the split tensile strength test setup are showed in Fig. 7 and Fig. 8, respectively.

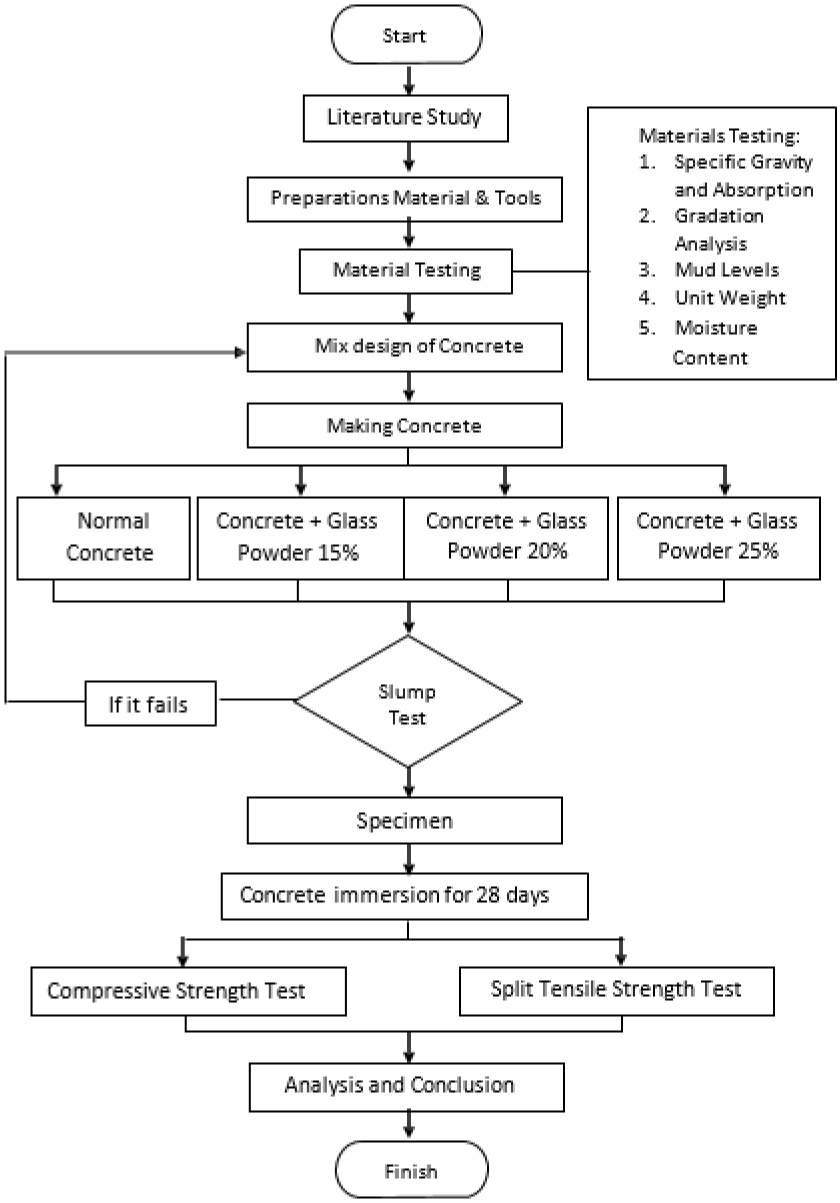

Fig. 1 Study methodology

Table 1 Mix design

Concrete type	Volume (1 mixture) (m^3)	Material compositions				
		Cement (kg)	Fine aggregate		Coarse aggregate (kg)	Water (kg)
			Sand (kg)	Glass Powder (kg)		
NC	0.03179	16.294	100%	-	10.386	7.837
			14.934	-		
GPC 10%	0.03179	16.294	90%	10%	10.386	7.837
			13.441	1.493		
GPC 15%	0.03179	16.294	85%	15%	10.386	7.837
			12.694	2.240		
GPC 20%	0.03179	16.294	80%	20%	10.386	7.837
			11.947	2.987		
Total		65.176	53.016	6.720	161.544	31.348

Fig. 2 Coarse aggregate

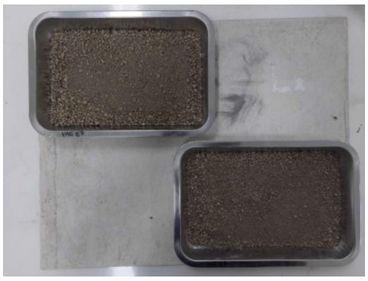

Fig. 3 Fine aggregate

Fig. 4 Glass powder

Fig. 5 Concrete molding process

Fig. 6 Concrete Specimens

Fig. 7 Compressive strength test

Fig. 8 Split tensile strength test

3. Results and Discussion

Based on the results of the slump test, all slump values in glass powder concrete and normal concrete in this study have an average value of 9.8 cm – 13.0 cm and this is in accordance with the design target of 6 cm – 18 cm (Fig. 9). The compressive strength (f_c') and split tensile strength (f_{ct}') test results on the glass powder concrete and normal concrete specimens are shown in Table 2. According to the compressive strength test results shown in Table 2 and Fig. 10, it shows that the compressive strength of glass powder concrete increases with increasing the content of glass powder. Where glass powder concrete GPC 20% increased by 11.32% with a value of 38.97MPa compared to the compressive strength of normal concrete with a value of 35.01 MPa. Meanwhile, GPC 15% and GPC 10% have the compressive strength of 38.03 MPa and 36.23 MPa, respectively. All glass powder concretes indicate higher compressive strength compared to the normal concrete. Based on the split tensile strength test results in Table 2 and Fig. 11, the glass powder concrete GPC 20% indicated the highest increase of 15% with a value of 2.71 MPa compared to normal concrete split tensile strength with a value of 2.36 MPa.

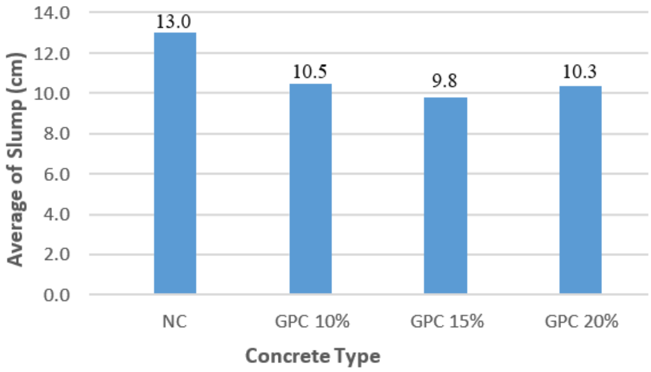

Fig. 9 Slump value of the glass powder concrete and normal concrete

Table 2 Compressive strength and split tensile strength tests result

Concrete type	Specimen	Compressive strength (f_c')	Average f_c'	Split tensile strength (f_{ct}')	Average f_{ct}'
		(MPa)	(MPa)	(MPa)	(MPa)
NC	1	33.97	35.01	2.12	2.36
	2	35.10		2.41	
	3	35.95		2.55	
GPC 10%	1	36.23	36.23	2.41	2.62
	2	35.39		2.83	
	3	37.08		2.62	
GPC 15%	1	37.37	38.03	2.55	2.55
	2	38.50		2.83	
	3	38.22		2.26	
GPC 20%	1	39.63	38.97	2.97	2.71
	2	38.50		2.69	
	3	38.78		2.48	

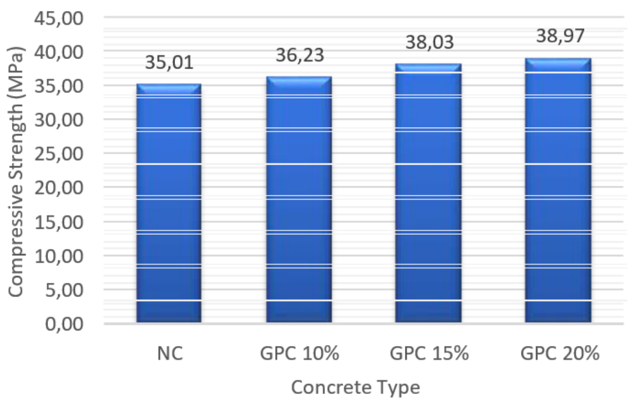

Fig. 10 Compressive strength test result

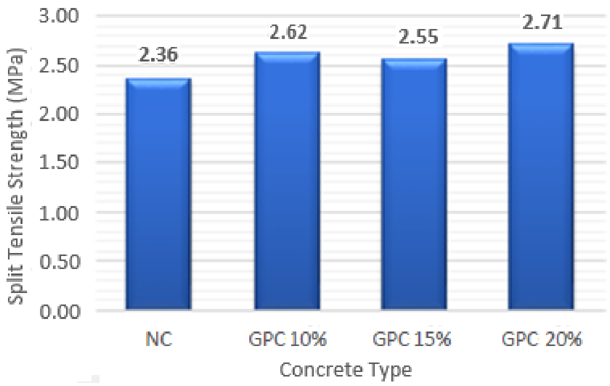

Fig. 11 Split tensile strength test result

4. Conclusions

This study has investigated the mechanical properties of concrete namely the compressive and split tensile strength of concrete with glass powder as a partial substitution of fine aggregates with a percentage of 10%, 15%, and 20% at a concrete age of 28 days. Based on the test results, it indicated that the compressive strength and split tensile strength of glass powder concrete increase with increasing the content of glass powder.

The compressive strength of concrete with 20% of glass powder content (GPC 20%) showed the highest increase of 11.32% compared to the normal concrete (NC) compressive strength. An increase was also shown in the split tensile strength. The concrete with glass powder content of 20% (GPC 20%) showed the highest increase of 15% compared to normal concrete (NC) split tensile strength. The results showed that the use of glass powder as a partial replacement for fine aggregate in this study was reasonably good to improve the mechanical properties of concrete in terms of compressive strength and split tensile strength.

References

[1] J. Widjajakusuma, I. Bali, G. P. Ng, and K. A. Wibowo, “An Experimental Study on the Mechanical Properties of Low-Aluminum and Rich-Iron-Calcium Fly Ash-Based Geopolymer Concrete,” Advances in Technology Innovation, vol. 7, no. 4, pp. 295-302, 2022.

[2] H. Du and K. H. Tan, “Properties of High-Volume Glass Powder Concrete,” Cement and Concrete Composites, vol. 75, pp. 22–29, 2017.

[3] W. Kushartomo, I. Bali, and B. Sulaiman, “Mechanical Behavior of Reactive Powder Concrete with Glass Powder Substitute,” Procedia Engineering, vol. 125, pp. 617-622, 2015.

[4] I. Bali, W. Kushartomo, and Jonathan, “Effect of In-Situ Curing on Compressive Strength of Reactive Powder Concrete,” MATEC Web of Conferences, vol. 67 (03013), pp. 1-6, 2016.

[5] I. Bali and W. Kurnia, “The Curing Method Influence on Mechanical Behavior of Reactive Powder Concrete,” International Journal on Advanced Science, Engineering and Information Technology, vol. 8, no. 5, pp. 1976-1983, 2018. [Online]. Available: http://dx.doi.org/10.18517/ijaseit.8.5.4197.

[6] N. Hanafiah, Pengaruh Penambahan Bubuk Kaca sebagai Bahan Pengganti Sebagian Semen dengan Variasi 2%, 4%, 6% dan 8% terhadap Kuat Tekan dan Nilai Slump, Teknik Sipil, Universitas Muhammadiyah Yogyakarta, Yogyakarta, 2011. (In Indonesian)

[7] I. Bali and A. Prakoso, “Beton Abu Sekam Padi sebagai Alternatif Bahan Konstruksi,” Jurnal Sains dan Teknologi EMAS, vol. 12, no. 29, pp. 75-81, 2002. (In Indonesian)

[8] I. Bali and F. Sitorus, “Merapi Volcanic Ash as an Eco-Material of Concrete Filler,” The 8th International Symposium on Lowland Technology, Bali, Indonesia, 2012.

[9] I. Bali and O. Sitorus, “The Effect of Cold Lava Aggregate as a Filler Material of Concrete,” The 3rd International Conference of European Asian Civil Engineering Forum (EACEF), Yogyakarta, Indonesia, 2011.

[10] B. P. Nugraha, E. T. Sudjatmiko, and I. Bali, "Compressive Strength of Concrete Containing Recycled Glass Powder," PRESUNIVE Civil Engineering Journal, vol. 1, no. 1, pp. 8-12, April 2023.

[11] R. H. Geovenerdy, I. Bali, and E. T. Sudjatmiko, "The Effect of Steam Curing on the Early Compressive Strength of Glass Powder Concrete," PRESUNIVE Civil Engineering Journal, vol. 1, no. 2, pp. 48-53, Oktober 2023.

[12] SIPSN, "Waste Composition in Indonesia," National Waste Management Information System (SIPSN) of the Ministry of Environment, Indonesia, 2022. https://sipsn.menlhk.go.id/sipsn/public/data/komposisi. (In Indonesian)

[13] A. Suwardih, Pengaruh Variasi Ukuran Butir Agregat Kasar (10 mm, 15 mm, dan 20 mm) dengan Penambahan Superplasticizer 1,5% dan Limbah Las Karbit terhadap Kuat Tekan Beton Mutu Tinggi, Fakultas Teknik Universitas Muhammadiyah Yogyakarta, Yogyakarta, 2017. (In Indonesian)

[14] American National Standards Institute, Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM C-39, USA: Annual Books of ASTM, 1993.

[15] American National Standards Institute, Test Method for Split Tensile Strength of Cylindrical Concrete Specimens, ASTM C 496 – 96, USA: Annual Books of ASTM, 2011.

[16] Badan Standardisasi Nasional, Persyaratan Beton Struktural untuk Bangunan Gedung, SNI 2847:2013, Jakarta, 2013. (In Indonesian)

[17] Badan Standardisasi Nasional, Tata Cara Pembuatan Rencana Campuran Beton Normal, SNI 03-2834-2000, Jakarta, 2000. (In Indonesian)

[18] Badan Standardisasi Nasional, Spesifikasi Bahan Bangunan Bagian A (Bahan Bangunan Bukan Logam), SK. SNI S-04-1989-F, Bandung: Lembaga Penyelidikan Masalah Bangunan, 1989. (In Indonesian)