The Effect of Steam Curing on the Early Compressive Strength of Glass Powder Concrete

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Abstract

Glass bottle waste is non-biodegradable and concerns about its impact on the environment. One alternative is to use recycled glass bottle waste in a form of glass powder as a partial replacement for fine aggregate in concrete. This study compared the glass powder concrete containing 20% glass powder as a partial replacement for fine aggregate treated by steam curing to the normal concrete treated by immersion curing. To obtain a higher early strength, the glass powder concrete will be treated with steam curing method for total duration of 9 hours. The test results showed that glass powder concrete treated with steam curing experienced a significant increase of 40.7% in compressive strength at 1 day of age with a compressive strength of 7.84 MPa compared to normal concrete of 5.56 MPa, an increase of 57.0% at 3 days of age with a compressive strength of 16.88 MPa compared to normal concrete of 10.75 MPa, and an increase of 14.0% at 7 days of age with a compressive strength of 23.86 MPa compared to normal concrete of 20.94 MPa. The results of this study indicated that steam curing has the effect of increasing the early compressive strength of concrete at the age of 1, 3 and 7 days. In addition, the use of 20% glass powder as a partial replacement for fine aggregate can contribute to the utilization of non-biodegradable glass bottle waste.

Keywords: glass powder concrete, steam curing, compressive strength, recycled glass bottle

1. Introduction

Based on the National Waste Management Information System (SIPSN) of the Ministry of Environment and Forestry of The Republic of Indonesia (KLHK) the amount of waste at the end of 2022 was 19,451,900 tons/year with glass waste composition of 2% of the total waste [1]. Since glass bottles are non-biodegradable, they can cause environmental problems. In addition, to recycle it will be quite expensive.

Glass powder has a composition of chemical compounds such as SiO_2, Al_2O_3, Fe_2O_3, and CaO [2]. Based on this composition, glass powder has the same compounds as cement specifically CaO and Al_2O_3. Because of its pozzolanic properties, if it is finely ground, it can be used as a partial replacement for fine aggregate [3]. The amount of glass powder can affect the compressive strength of concrete because calcium hydroxide became insufficient for the pozzolanic reaction of glass powder after a 30% replacement [4].

As a partially substitute for cement, studies have been reported the use of glass powder as a partial replacement for cement in reactive powder concrete using the steam curing method at high pressure to obtain the highest compressive strength using 20% glass powder with the result of compressive strength of 136 MPa [5]. In-situ steam curing is also reported to increase the compressive strength of reactive glass powder concrete [6-7]. Another study reported the use of 15% glass powder using the

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normal curing method produces a compressive strength of 35.57 MPa [8].

Steam curing is proven to accelerate early strength on concrete [5, 9-10]. Maximum temperature lies in the range of 40℃ - 100℃. However, the optimum temperature has been found in the range of 65℃ - 85℃. The maximum temperature is a compromise between early strength gain and the ultimate strength, because the higher the curing temperature, the lower the ultimate strength [11].

In this study, recycled glass powder was used as a partial replacement of fine aggregate [12]. 20% glass powder is used as a partial replacement for fine aggregate. Steam curing method is applied for the glass powder concrete in order to accelerate the early strength of the concrete [9, 11, 13]. 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. Because to obtain pozzolanic properties, glass powder with very fine grains is needed [3]. The purpose of this study is to investigate the compressive strength of glass powder concrete treated with atmospheric pressure steam curing compared to normal concrete treated with immersion curing. In addition, this study encouraged by the environmental concern of using recycled glass bottle waste and the effect of steam curing on early strength acceleration on concrete.

2. Material and Method

This study aims to investigate the effect of steam curing on the performance of the mechanical properties of glass powder concrete compared to immersion curing on normal concrete. The percentage of glass powder used is 20% of the total volume of fine aggregate as a partial substitution. Standard cylindrical specimens aged 1, 3, 7, and 28 days used in compressive strength testing in this study [14-15]. Then, the results of the compressive strength are compared. The study methodology is shown in Fig. 1.

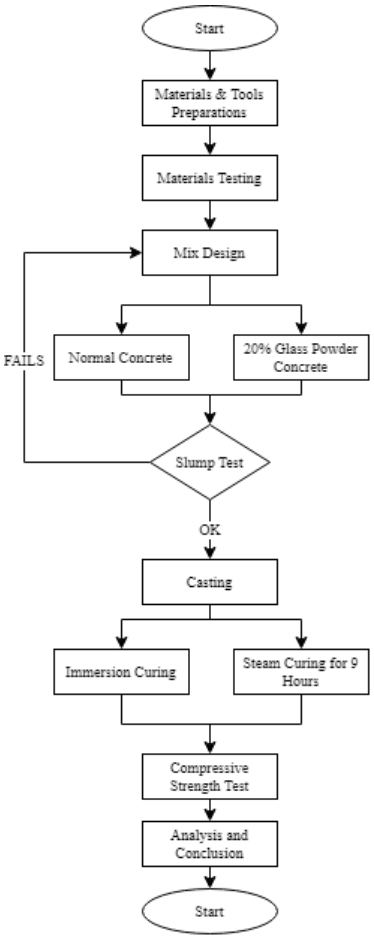

Fig. 1 Study methodology

The main materials in this study are cement, water, coarse aggregates, fine aggregates, and glass powder which will be described in this section. A brief description of the materials used is as follow [16-17], cement uses Portland Composite Cement (PCC) Type I as a binder for the concrete mixture, coarse aggregate uses crushed stone with the size 4.75 mm < Sieve Size < 15 mm (Fig. 2), fine aggregate uses sand passed 2.36 mm sieve size with Fineness Modulus (FM) = 2.134% (Fig. 3). The fine and coarse aggregate will be tested for specific gravity and absorption, mud levels, aggregate gradation, and aggregate moisture. The glass powder used is from waste glass bottles passing 0.075 mm < Sieve size < 0.150 mm (Fig. 4)

Concrete with 20% glass powder with steam curing treatment will be compared with normal concrete with normal curing treatment in terms of compressive strength. The glass powder concrete will be treated with steam curing at atmospheric pressure for 9 hours with 2 hours of heating period, 5 hours of maximum temperature period, and 2 hours of cooling down period. The maximum temperature will be in the range of 60°C to 80°C. The number of specimens is 24 in 1, 3, 7, 28 days of age (each variation has 3 samples). The mix design of glass powder concrete can be seen in Table 1. The concrete specimens used in this study are cylinders with a diameter Ø = 150 mm and h = 300 mm (Fig. 5). For the curing method is using the steam curing method (Fig. 6) and immersion curing method (Fig. 7). The compressive strength test setup is showed in Fig. 8.

Table 1 Mix design

Code	Total Specimens	Volume (1 specimen) (m^3)	Material Compositions				
			Cement (Kg)	Fine Aggregate (Kg)		Coarse Aggregate (Kg)	Water (Kg)
				Sand (Kg)	Glass Powder (Kg)		
Normal Concrete-1 Day	3	0.00556	8.60	7.58	-	19.03	3.61
Normal Concrete-3 Day	3	0.00556	8.60	7.58	-	19.03	3.61
Normal Concrete-7 Day	3	0.00556	8.60	7.58	-	19.03	3.61
Normal Concrete-28 Day	3	0.00556	8.60	7.58	-	19.03	3.61
Glass Powder Concrete 20%-1 Day	3	0.00556	8.60	6.07	1.51	19.03	3.61
Glass Powder Concrete 20%-3 Day	3	0.00556	8.60	6.07	1.51	19.03	3.61
Glass Powder Concrete 20%-7 Day	3	0.00556	8.60	6.07	1.51	19.03	3.61
Glass Powder Concrete 20%-28 Day	3	0.00556	8.60	6.07	1.51	19.03	3.61
Total	24		68.84	54.63	6.07	152.31	28.88

Fig. 2 Coarse aggregate

Fig. 3 Fine aggregate

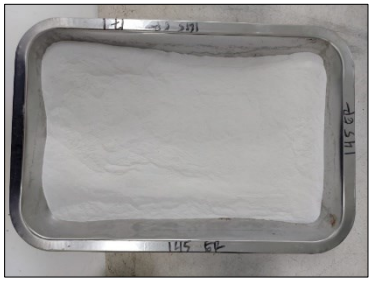

Fig. 4 Glass powder

Fig. 5 Cylindrical mould, dimension of 150 mm × 300 mm

Fig. 6 Steam curing

Fig. 7 Immersion curing

Fig. 8 Compressive strength test

3. Results and Discussion

All slump values in glass powder concrete and normal concrete in this study have an average value of 7 cm – 12.3 cm and this is in accordance with the design target of 6 cm – 18 cm (Fig. 9). The compressive strength test results (f_c') on the glass powder concrete and normal concrete specimens are shown in Table 2. From the data in Table 2, the compressive strength of glass powder concrete with steam curing treatment increases significantly at the age of 1, 3, and 7 days. Whereas at the age of 28 days, there was a decrease in 20% glass powder concrete with steam curing.

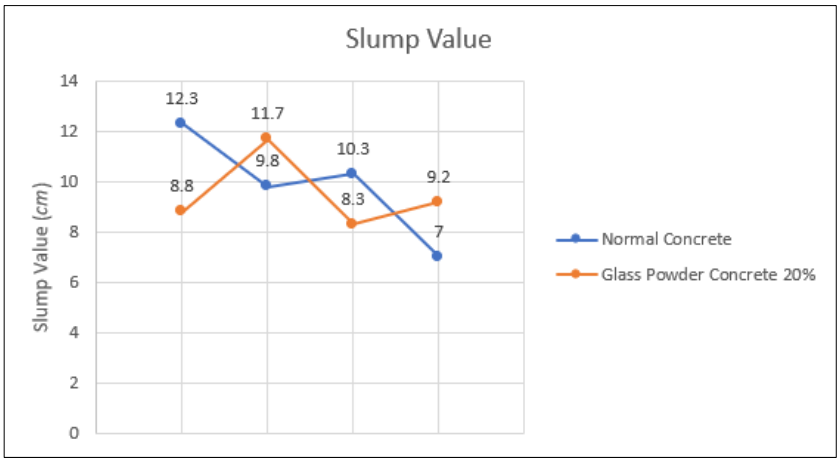

Fig. 9 Slump value of the glass powder concrete and normal concrete

Table 2 Compressive strength test result

Compressive Strength Test Result		
Concrete Type	Cylinder specimen Ø × h (mm)	Average f_c' (MPa)
Normal Concrete-1 Day	150 × 300	5.56
Glass Powder Concrete 20%-1 Day		7.83
Normal Concrete-3 Day		10.75
Glass Powder Concrete 20%-3 Day		16.88
Normal Concrete-7 Day		20.94
Glass Powder Concrete 20%-7 Day		23.86
Normal Concrete- 28 Day		33.48
Glass Powder Concrete 20%-28 Day		28.95

The average compressive strength of steam cured concrete with 20% glass powder at 1, 3, and 7 days of age indicates an increase in early strength gain compared to normal cured concrete, 40.7%, 57.0%, and 14.0%, respectively. Based on the test result, concrete with 20% glass powder at 3 days of age proved to experience highest increase in early strength as much 57.0% compared to normal concrete. However, at the age of 28 days, concrete with 20% glass powder experienced a decrease of 13.53% in compressive strength compared to normal concrete.

4. Conclusions

This study has presented the compressive strength test of the glass powder concrete with 20% glass powder as a partial replacement of fine aggregate treated by steam curing, compared to normal concrete treated by normal curing. According to the results, the following conclusions can be obtained. The average compressive strength of steam cured concrete with 20% glass powder at 1, 3, and 7 days of age indicates an increase in early strength gain compared to normal cured concrete, with an increase of 40.7%, 57.0%, and 14.0%, respectively. These values indicate that steam curing can increase early strength gain on concrete. Whereas, at the age of 28 days of age, steam cured concrete with 20% glass powder experienced a decrease of 13.53% in compressive strength compared to normal cured concrete.

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