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A predictive model for compressive strength of waste LCD glass concrete by nonlinear-multivariate regression

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Abstract. The purpose of this paper is to develop a prediction model for the compressive strength of waste LCD glass applied in concrete by analyzing a series of laboratory test results, which were obtained in our previous study. The hyperbolic function was used to perform the nonlinear-multivariate regression analysis of the compressive strength prediction model with the following parameters: water-binder ratio *w/b*, curing age t, and waste glass content G. According to the relative regression analysis, the compressive strength prediction model is developed. The calculated results are in accord with the laboratory measured data, which are the concrete compressive strengths of different mix proportions. In addition, a coefficient of determination R^2 value between 0.93 and 0.96 and a mean absolute percentage error MAPE between 5.4% and 8.4% were obtained by regression analysis using the predicted compressive analysis value, and the test results are also excellent. Therefore, the predicted results for compressive strength are highly accurate for waste LCD glass applied in concrete. Additionally, this predicted model exhibits a good predictive capacity when employed to calculate the compressive strength of washed glass sand concrete.

Keywords: compressive strength; concrete; prediction model; waste glass; regression

1. Introduction

Liquid crystal glass is currently a rising sector of the high-tech industry in Taiwan. With the highest market share of TFT-LCD (thin film transistor-liquid crystal display) in the world, 43% in 2007,Taiwan was the key worldwide manufacturer of panel displays (Tseng 2009). However, with the soaring output of TFT-LCD, the manufacturing process has produced a large amount of waste. The output of waste LCD glass in Taiwan was as high as 20,000 tons in 2007.

The main chemical constituents of waste LCD glass are SiO_2, Na_2O and a small amount of indium-tin-oxide conducting film. The conducting film is coated on LCD to reduce the resistance of the

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substrate surface in order to enhance the light transmittance and conductivity. Therefore, direct landfill, incineration or composting treatment is in appropriate for waste LCD glass (Lin 2007). The glass contains a large amount of silicon and calcium and is Portland material by nature. Its physical properties, such as unit weight, compressive strength, elasticity modulus, thermal expansion coefficient and heat transfer coefficient, are very close to concrete. Thus, adding the crushed waste glass to concrete as a fine aggregate can reduce the air content and unit weight of concrete (Topcu and Canbaz 2004). The waste glass recycling can reduce the material cost and the impact on the environment as well as CO_2 emission, which are preferred outcomes for sustainable environmental protection.

Although many studies have discussed concrete made with waste glass, most of them focus on the compressive strength, ultrasonic pulse velocity, surface resistance, shrinkage, durability and workability (Topcu and Canbaz 2004, Kin 2007, Wang and Chen 2008, Bashar and Ghassan 2009, Lin *et al.* 2009, Wang and Huang 2010a, Chen *et al.* 2011, Wang 2011, Lin *et al.* 2012) and seldom discuss the prediction model and regression analysis of the compressive strength of the concrete.

Therefore, based on the results of our previous studies on the mixture ratios of concrete made with waste LCD glass (Wang and Huang 2010a, b), this study aims to determine the relationships between the multiple influencing factors of compressive strength, waste glass content, water-binder ratio and age. Moreover, a predictive analysis model was established for evaluating the compressive strength.

2. Characteristics of glass and waste LCD glass concrete

Topcu and Canbaz (2004) used waste glass with a unit weight of 1493 kg/m^3~2400 kg/m^3 and a particle diameter of approximately 4 mm to 16 mm to replace coarse aggregate. The slump, air content and unit weight of the concrete decreased as the proportion of additional waste glass increased, but the slump flow related to the workability increased. In addition, the mechanical properties of concrete, such as the compressive strength, flexural strength, splitting tensile strength and dynamic modulus of elasticity decreased as the waste glass content increased. The concrete expansion slowed down as the addition of waste glass content increased. Terro (2006) observed the same trend in waste glass concrete using recycled crushed glass with different particle diameters as an aggregate.

Kou and Poon (2009) used recycled glass sand with a particle diameter less than 5 mm, a specific gravity of 2.45 and a fineness modulus of 4.25 to study self-consolidating concrete (SCC). The findings indicated that the unit weight and air content decreased as the level of added waste glass increased. However, the decrease in amplitude was small, and the variance in slump flow was slightly influenced by the waste glass content. In addition, expansion increased slowly as the level of added waste glass increased. The trends of slump flow and ASR test result (Kou and Poon 2009) were slightly different from the results of Topcu and Canbaz (2004). As for mechanical properties, the compressive strength, splitting tensile strength and static elasticity modulus decreased as the waste glass content increased. Wang *et al.* (2011) found that the slump flow increased with the replacement of glass additive as an aggregate, but the compressive strength decreased as the level of added glass increased. The compressive strength of waste LCD glass concrete also decreased as the replacement with waste glass increased (Park *et al.* 2004, Wang and Chen 2008, Wang 2009, Wang 2011, Lin *et al.* 2012). However, the compressive strength of the brick sintered at 900℃ to 1000℃ by replacing clay with waste LCD glass powder increased with the waste LCD glass content (Lin *et al.* 2007). This trend differed from the observed mechanical properties of general recycled glass and waste LCD glass concrete.

As mentioned above, the compressive strength of the concrete with the replacement of recycled glass, waste glass or waste LCD glass as aggregates primarily decreases as the addition level increases. In addition, the compressive strength of the concrete with waste glass is similar to behavioral characteristics of general concrete; the compressive strength increases with the curing time. However, after a certain age, the increase in compressive strength becomes smooth. Similarly, the compressive strength decreases as the water-binder ratio increases.

3. Experimental materials and mixture

This study integrated a series of test results with different mixture ratios of self-compacting waste LCD glass concrete to discuss the relationships between the multiple influencing factors of compressive strength, waste glass content, water-binder ratio and age to establish a predictive analysis model for evaluating the compressive strength. The material properties and mixture content ratios are briefly described below (Huang 2009, Wang and Huang 2010a, b).

The cement, fly ash, and slag used in this study were local materials complying with the specifications in CNS61, CNS3036, and CNS12549, respectively. Particulate waste glass sand, able to pass through a No. 8 sieve, was provided by Chi Mei Optoelectronics. The physical properties of the aggregate and glass sand are shown in Table 1, and Type 1000 superplasticizer complying with the ASTM C494 type G admixture was used. The water-to-binder ratios were 0.28, 0.32, and 0.36, and four types of glass sand were added at volume replacement ratios of 0%, 10%, 20%, and 30%. Fly ash, water-quenched slag and superplasticizer were added and blended using a simple SCC mixing design method. The SCGC mixture proportions are shown in Table 2. In addition, the particle size distribution curves of the aggregate and glass sand are shown in Fig. 1. The compressive strength, flexural strength and ultrasonic pulse velocity, among other parameters, were measured.

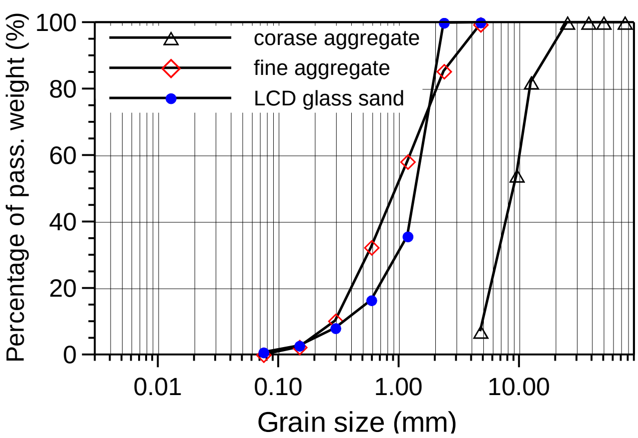


Fig. 1 Cumulative particles distribution of aggregate and LCD glass sand

Table 1 Physical properties of aggregate and glass sand

Items	Coarse aggregate	Fine aggregate	Glass sand	Regulatory
Particle density (g/cm^3)	2.62	2.57	2.45	ASTM C128 ASTM C127
Water absorption (%)	0.7	1.2	0.4	ASTM C128 ASTM C127
Fineness modulus (FM)	5.02	3.22	3.37	ASTM C136
D max (mm)	125	23.6	11.8	ASTM C136
Soil content (%)	0.5	1.3	—	ASTM C117
Unit weight (kg/m^3)	1530	1820	680	ASTM C29

Table 2 Mixture proportions of SCGC

w/*b*	No.	Substation (%)	Binding materials (kg/m^3)			Aggregate (kg/m^3)			Water content (kg/m^3)	
			Cement	Fly ash	Slag	Coarse aggregate	Sand	Glass sand	Water	SP
0.28	SC28G0	0	463	132	66	786	850	—	185	7.2
	SC28G10	10	463	132	66	786	765	74	185	7.2
	SC28G20	20	463	132	66	786	680	159	185	7.2
	SC28G30	30	463	132	66	786	595	238	185	7.2
0.32	SC32G0	0	420	116	58	786	850	—	185	6.5
	SC32G10	10	420	116	58	786	765	74	185	6.5
	SC32G20	20	420	116	58	786	680	159	185	6.5
	SC32G30	30	420	116	58	786	595	238	185	6.5
0.36	SC36G0	0	360	103	51	786	850	—	185	5.7
	SC36G10	10	360	103	51	786	765	74	185	5.7
	SC36G20	20	360	103	51	786	680	159	185	5.7
	SC36G30	30	360	103	51	786	595	238	185	5.7

4. Studying and planning of compressive strength prediction model and analysis of test results

4.1 Development of compressive strength prediction model

4.1.1 Modeling of normalized compressive strength

Murat *et al.* (2007) found that the compressive strength of fly ash concrete increased with age, but the trend became smooth over time. The relationship was an approximately horizontal curve after a certain age. The results of other studies on the compressive strength of concrete have revealed the same trend (Hwang *et al.* 1999, Murat *et al.* 2007, Lin *et al.* 2009, Vahid and

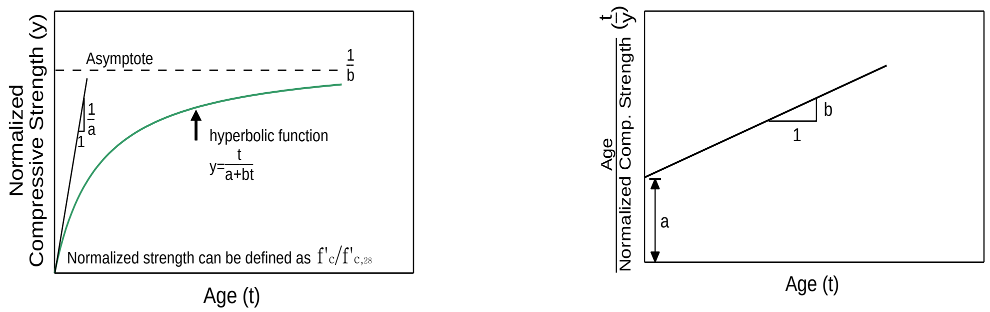
Mohammad 2010 , Lin *et al.* 2012, Mousavi *et al.* 2012). With respect to the influence of additives in concrete on the compressive strength, including the influence of replacement with fly ash, furnace slag and waste glass for partial cement or sandy soil under the same conditions, the compressive strength of the concrete with any additive increased with the age, and the increase in compressive strength became smooth over time. Duncan and Chang (1970) conducted a triaxial test on soil, and found that the nonlinear stress-strain relation of soil could be reasonably evaluated using the hyperbolic model. It was appropriately applied to the prediction and evaluation analyses of the soil stress-strain relation curve (Wang 2001). The trend of compressive strength and age of concrete is very similar to the hyperbolic model. As long as variables are changed appropriately, the hyperbolic model can be applied to predictive analysis to determine the trends in the compressive strength of concrete, and the results as shown in Fig. 2(a) and 2(b). Therefore, this study constructed a prediction model for the compressive strength of multivariate self-compacting waste LCD glass concrete considering the water-binder ratio *w*/*b*, age t and replacement percentage of waste glass G based on the hyperbolic model.

Fig. 3 shows the test result of a normalized ratio of compressive strength at different curing ages and on Day 28 with a water-binder ratio *w*/*b* of 0.28 and a waste glass replacement ratio G of 0~30%. For the same waste glass content G, the compressive strength f'_c increases with the age *t*, but the increase becomes smooth as the age increases further. Therefore, the relation between compressive strength and age is simulated by the hyperbolic model, as shown in Eq. (1).

$$y = \frac{f'_c}{f'_{c,28}} = f(t) = \frac{t}{a + bt} \tag{1}$$

where parameters a and b are the coefficients of hyperbolic function, and t is the age.

Here, 1/*a* represents initial slope of the strength curve. That is, it represents the growth of the initial strength. Additionally, 1/*b* represents the asymptotes of the strength curve, and 1/*b* represents the highest value of the compressive strength. Similar phenomena were observed in other tests with various water-binder ratios. Therefore, a detailed discussion on the relationships among parameters *a* and *b*, the waste glass content (*G*) and the water-binder ratio (*w*/*b*), was performed (shown in Table 3).



(a) Hyperbolic normalized compressive strength vs. curing age curve

(b) Transformed normalized compressive strength vs. curing age curve

Fig. 2 The characteristics of hyperbolic model

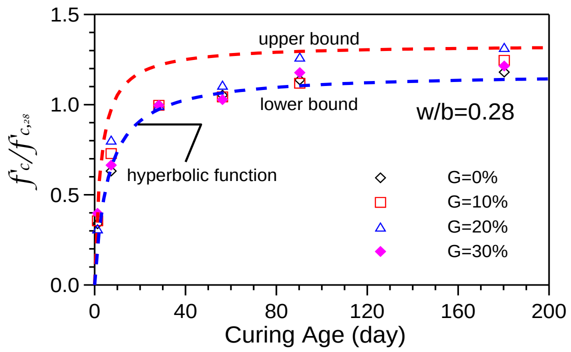


Fig. 3 Normalized compressive strength vs. curing time with different glass contents for *w*/*b* = 0.28

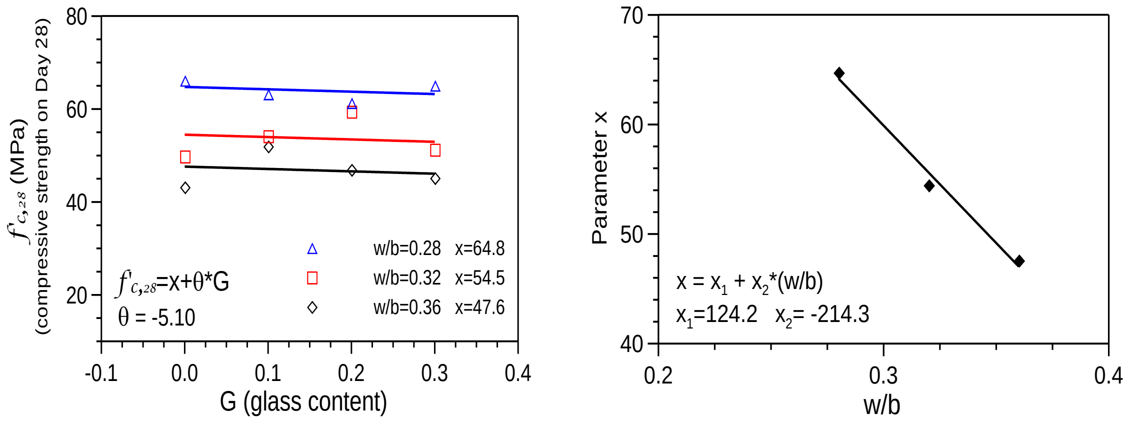
Table 3 Values of parameter *a* and *b* for different mixtures.

w/*b*	G	*a*	*b*
0.28	0	4.616	0.824
	0.1	5.538	0.787
	0.2	5.224	0.735
	0.3	4.952	0.800
0.32	0	5.510	0.645
	0.1	4.593	0.724
	0.2	5.877	0.732
	0.3	6.706	0.642
0.36	0	5.773	0.637
	0.1	4.560	0.773
	0.2	5.862	0.685
	0.3	4.964	0.703

4.1.2 Determine parameters of prediction model

The compressive strength of waste glass concrete decreases as the level of added waste glass increases (Park *et al.* 2004, Topuc and Canbaz 2004, Terro 2006, Wang and Chen 2008, Kou and Poon 2009, Wang 2009, Wang 2011, Wang *et al.* 2011, Lin *et al.* 2012). Therefore, the model used in this study assumes that the compressive strength of the waste glass concrete decreases as the waste glass content increases using the same mixture ratio.

Eq. (1) shows that under the same conditions, parameter a increases with the waste glass content, based on the assumption of compressive strength decreasing with a higher waste glass content. Thus, a linear increasing function between a and G was used and shows a parallel relationship with the change in waste glass content, as shown in Fig. 4(a). The sensitivity of parameter a is shown in Eq. (2), in which *a* was set as a constant. Furthermore, while a more detailed discussion was carried out on the relationship between parameters m and water-binder ratio *w*/*b*. Fig. 4(b) showed that the parameters m and *w*/*b* also exhibit a linear increasing relationship, as approximated in Eq. (3). Table 3 shows that parameter b did not affected by various waste glass contents; therefore, no relationship is found as shown in Fig. 4(c) and the



(e) Compressive strength on Day 28 vs. glass content with different water-binder ratio

(f) Parameter *x* vs. water-binder ratio *w*/*b*

Fig. 4 The characteristics of parameters of predicted model

sensitivity of parameter *ß* expressed as Eq. (4). Similarly, a linear decreasing relationship (illustrated in Fig. 4(d)) between the parameter n and the water-binder ratio *w*/*b* is shown in Eq. (5).

$$a = f(G) = (m + \alpha \times G) \tag{2}$$

$$m = (m_1 + m_2(w/b)) \tag{3}$$

$$b = f(G) = (n + \beta \times G) \tag{4}$$

$$n = (n_1 + n_2(w/b)) \tag{5}$$

Where *a*, *ß* m and n are the parameters related to waste glass content G, an m_1, m_2 and n_1, n_2 are the coefficients related to water-binder ratio (*w*/*b*). Eq. (2) to Eq. (5) are combined, and Eq. (1) can be expressed as Eq. (6) and Eq. (7). Fig. 4(e) is the compressive strength on 28 day of mixtures with different water-binder ratios versus waste glass content. The relationship showed that the compressive strength on Day 28 ($f'_{c,28}$) and waste glass content G exhibit both of linear decreasing and parallel relationship, the evaluation method for compressive strength on Day 28 is derived and expressed as Eq. (8). In addition, a linear decreasing relationship between the parameters *x* and the water-binder ratio *w*/*b* is shown in Fig. 4(f), and can be derived in Eq. (9). When the prediction model for compressive strength of concrete is used for the model regression analysis of the test results, the model parameters are $\alpha = 1.48$, *ß* = 0, θ = -5.10, m_1=4.30, m_2=2.58, n_1 = 1.07, n_2 = -1.09, x_1 = 124.2, x_2 = -214.3 and tabulated in Table 4.

$$\frac{f'_c}{f'_{c,28}} = \frac{t}{(m + \alpha \times G) + (n + \beta \times G)t} \tag{6}$$

$$\frac{f'_c}{f'_{c,28}} = \frac{t}{[(m_1 + m_2(w/b)) + \alpha \times G] + [(n_1 + n_2(w/b)) + \beta \times G] \times t} \tag{7}$$

$$f'_{c,28} = x + \theta \times G \tag{8}$$

$$x = (x_1 + x_2(w/b)) \tag{9}$$

4.2 Comparison between predictive analysis and test result of compressive strength

Fig. 5 through Fig. 7 show the test results for the compressive strength of self-compacting waste LCD glass concrete with the replacement of waste LCD glass for the fine aggregate (sandy soil) by weight percentages G of 0%, 10%, 20% and 30%, respectively, in different water-binder ratios. The comparison of predicted values of compressive strength by the model with the actual experimental values was shown in Table 5. As shown, when the water-binder ratio w/b is 0.28, the compressive strength of the specimen decreases slightly as the waste glass content increases at the same age. However, the change is not apparent, and the strength is distributed over a range. In addition, if the compressive strength at the age of 28 days is taken as standard ($f'_{c,28}$), the compressive strength on Day 7 ($f'_{c,7}$) is 64% to 81% of the strength on Day 28, and the compressive strength on Day 90 ($f'_{c,90}$) is 112% to 127% of the strength on Day 28. When the water-binder ratio w/b is 0.32, the compressive strength ratio $f'_{c,7}/f'_{c,28}$ is distributed from 71% to

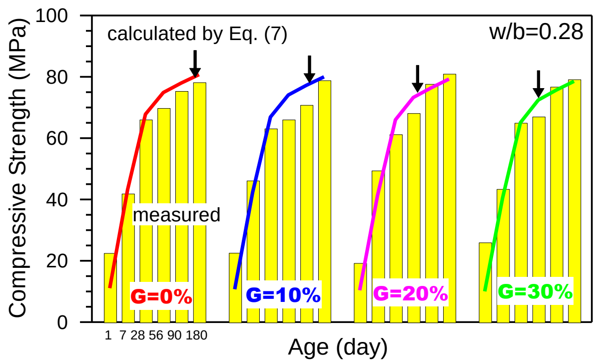


Fig. 5 Comparison results of experimental value and predicted model for water-binder ratio of 0.28

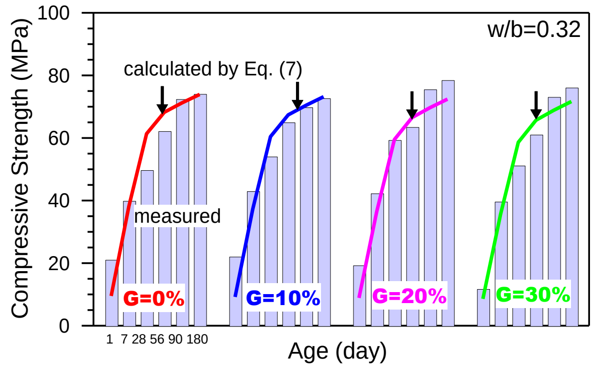


Fig. 6 Comparison results of experimental value and predicted model for water-binder ratio of 0.32

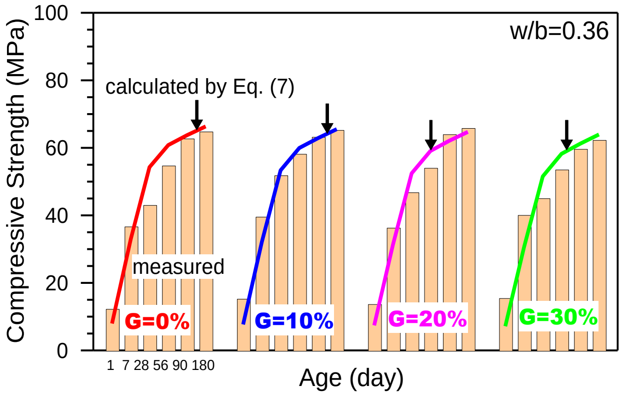


Fig. 7 Comparison results of experimental value and predicted model for water-binder ratio of 0.36

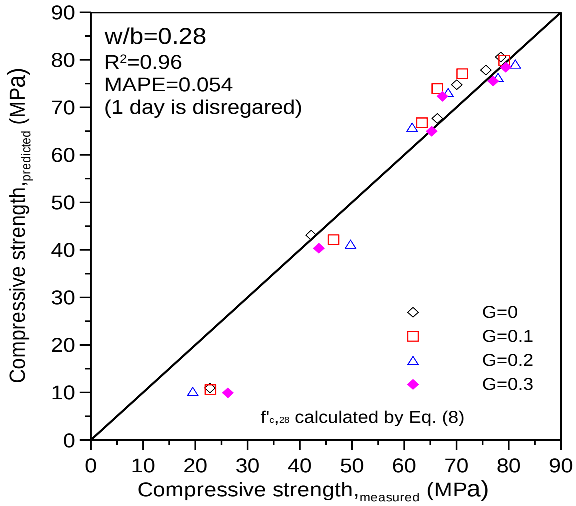


Fig. 8 Comparison of the predicted and measured strength for water-binder ratio of 0.28

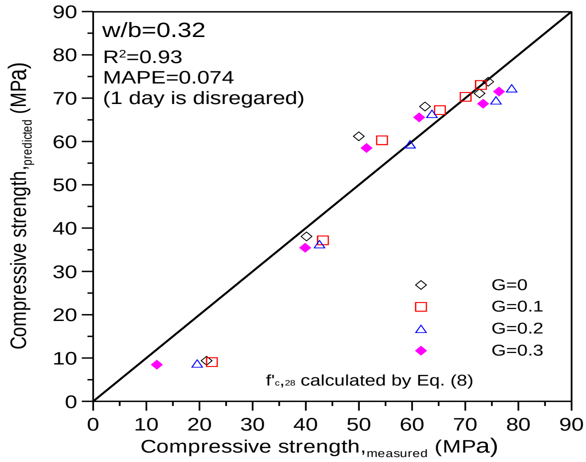


Fig. 9 Comparison of the predicted and measured strength for water-binder ratio of 0.32

80%, and $f'_{c,90}/f'_{c,28}$ is distributed from 127% to 146%. When the water-binder ratio *w*/*b* is 0.36, the compressive strength ratio $f'_{c,7}/f'_{c,28}$ is distributed from 75% to 90%, and $f'_{c,90}/f'_{c,28}$ is distributed from 122% to 146%.

As shown in Fig. 5 through Fig. 7, the multivariate concrete compressive strength prediction model considering the water-binder ratio *w*/*b*, age *t* and waste glass content *G* utilized in the previous section is used to compare the prediction regression analysis with the test results. The compressive strength prediction model based on the hyperbolic model can accurately evaluate the compressive strength at different *w*/*b*, *t* and *G* conditions. Thus, the strength analysis value of the prediction model can be overrated and underrated at times, but the result of the overall analysis is reasonable. When the water-binder ratio *w*/*b* is 0.28, the compressive strength ratio $f'_{c,7}/f'_{c,28}$ is 63% to 68%, and $f'_{c,90}/f'_{c,28}$ is 120% to 122%. When the water-binder ratio *w*/*b* is 0.32, $f'_{c,7}/f'_{c,28}$ is 65% to 69%, and $f'_{c,90}/f'_{c,28}$ is 127% to 128%. When the water-binder ratio *w*/*b* is 0.36, $f'_{c,7}/f'_{c,28}$ is 67% to 70%, and $f'_{c,90}/f'_{c,28}$ is 134% to 136%.

In addition, to determine the error between the model analysis result and the measured value, the MAPE (mean absolute percentage error) of Eq. (10) can be used for the evaluation (Lewis, 1982). A MAPE less than 20% means that the model has good predictive ability. Table 6 shows the four degree MAPE suggested by Lewis (1982). The analytic result shows when the water-binder ratios *w*/*b* are 0.28, 0.32 and 0.36 and the test result at the age of one day is disregarded, the MAPE values are 5.4%, 7.4% and 8.4%, respectively. It is worth mentioning that the derived process of predicted model of this study is based on the hyperbolic function, and the trend of this curve would be slowly grown from the origin of the coordinates by nonlinear relationship, as shown in Fig. 2(a). However, the compressive strength of concrete would immediately increase after final setting time arrival (in general, it would be within 24 hours), because of the concrete material just from fresh to harden state. Therefore, it will have more error between the measured and predicted strength in the initial state of curing time. Thus, the tested results of compressive strength of initial curing time, such as 1 day or 3 day, would be ignored when the values of predicted and tested strength are compared. According to the error analysis, the MAPE values of the compressive strength prediction model reported in this paper are less than 10%, meaning that the model's predictive ability is excellent.

$$\mathrm{MAPE} = \frac{1}{k}\sum_{i=1}^{k}\left|\frac{y_i - \hat{y}_i}{y_i}\right| \tag{10}$$

where y_i = measured value, $\hat{y}_i$ = model analysis value, and k = number of analytic data.

As shown in Fig. 8 through Fig. 10, the coefficient of determination R^2 obtained from regression analysis using the model for the predicted compressive strength analysis value and the test result shows excellent accuracy. When *w*/*b* is 0.28, $R^2 = 0.96$; when *w*/*b* is 0.36, $R^2 = 0.95$. When *w*/*b* is 0.32, $R^2 = 0.93$. Notably, Mousavi *et al.* (2012) studied high performance concrete and found that when comparing between the analytical result of a prediction model and the experimental value, if the coefficient of determination R^2 value is greater than 0.8, there is an excellent correlation. Furthermore, the established model can well predict compressive strength of washed glass sand concrete performed by Limbachiy a in 2009. Fig. 11 through Fig. 14 illustrate the

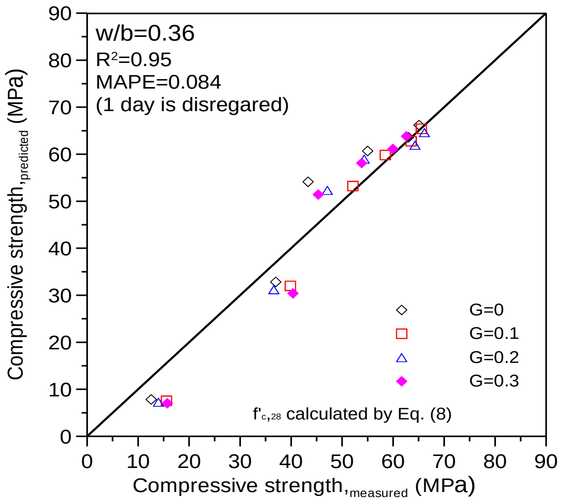


Fig. 10 Comparison of the predicted and measured strength for water-binder ratio of 0.36

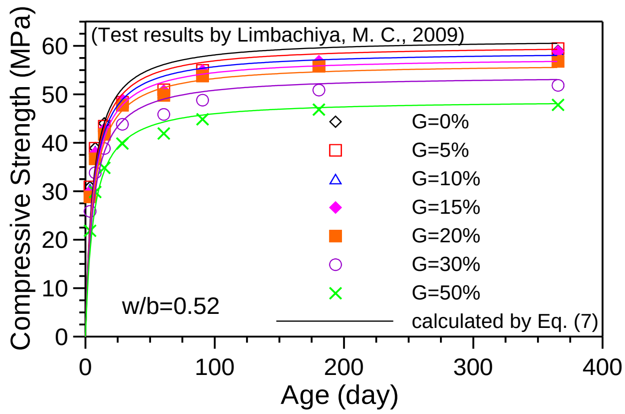


Fig. 11 Comparison results of predicted model and test results performed by Limbachiya (2009)(*w*/*b* = 0.52)

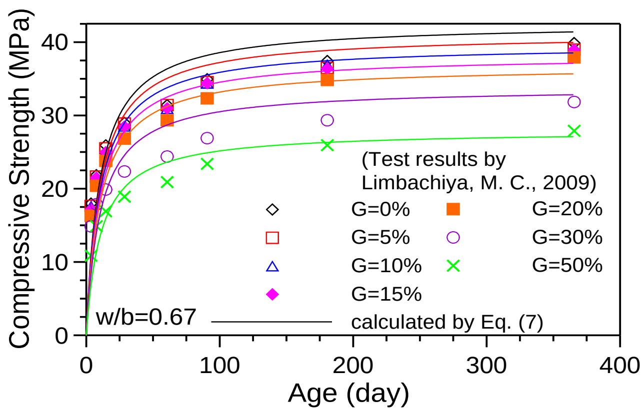


Fig. 12 Comparison results of predicted model and test results performed by Limbachiya (2009)(*w*/*b* = 0.67)

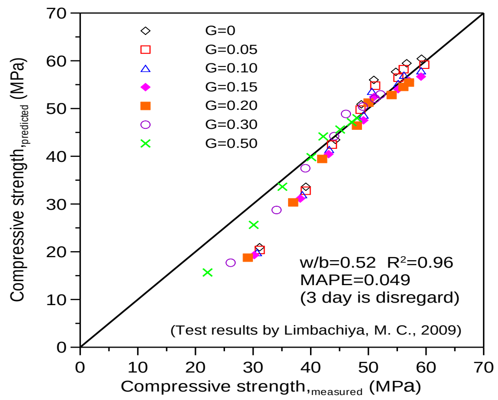


Fig. 13 Relationship between predicted compressive strength and test results performed by Limbachiya (2009)(*w/b* = 0.52)

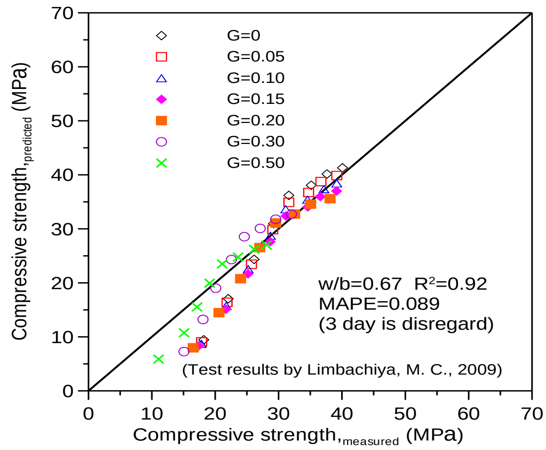


Fig. 14 Relationship between predicted compressive strength and test results performed by Limbachiya (2009)(*w/b* = 0.67)

Table 4 The value of parameters of predicted model

parameters	waste LCD glass concrete (this study)	washed glass sand concrete (Limbachiya 2009)
a	1.48	0.88
$ß$	0	0
θ	-5.10	-20.71
m_1	4.30	-4.23
m_2	2.58	17.25
n_1	1.07	1.23
n_2	-1.09	-0.78
x_1	124.2	121.7
x_2	-214.3	-136.7

Table 5 Comparison of predicted values of compressive strength by the model with the actual experimental values

w/b	No.	Tested compressive strength (MPa)						Predicted compressive strength (MPa)					
	Age (day)	1	7	28	56	90	180	1	7	28	56	90	180
0.28	SC28G0	22.67	42.05	66.19	69.93	75.50	78.35	11.09	43.23	67.80	74.89	77.97	80.71
	SC28G10	22.75	46.32	63.26	66.20	70.97	79.01	10.72	42.28	66.89	74.07	77.20	79.99
	SC28G20	19.38	49.58	61.38	68.27	77.82	81.13	10.38	41.36	65.98	73.25	76.43	79.26
	SC28G30	26.11	43.52	65.12	67.17	76.89	79.30	10.05	40.47	65.09	72.44	75.66	78.54
0.32	SC32G0	21.21	40.00	49.84	62.30	72.55	74.19	9.50	38.19	61.33	68.21	71.23	73.93
	SC32G10	22.21	43.10	54.21	65.10	69.94	72.82	9.18	37.30	60.41	67.37	70.43	73.17
	SC32G20	19.44	42.44	59.48	63.61	75.65	78.60	8.88	36.44	59.51	66.53	69.63	72.41
	SC32G30	11.84	39.76	51.30	61.20	73.23	76.23	8.59	35.59	58.61	65.70	68.84	71.66
0.36	SC36G0	12.44	36.85	43.21	54.87	62.90	64.96	7.96	32.96	54.26	60.81	63.71	66.32
	SC36G10	15.43	39.73	51.99	58.34	63.40	65.41	7.68	32.13	53.35	59.94	62.88	65.53
	SC36G20	13.86	36.48	46.97	54.20	64.15	65.99	7.41	31.32	52.44	59.09	62.06	64.74
	SC36G30	15.61	40.24	45.20	53.69	59.82	62.48	7.16	30.53	51.55	58.23	61.23	63.94

Table 6 The criterion for the MAPE

MAPE (%)	model's predictive ability
< 10	Excellent
10 - 20	Good
20 - 50	Reasonable
> 50	Incorrect

relationship between the predicted and observed strength with various testing ages. It is obviously seen that the strength calculated from predicted model is highly reasonable owing to the excellent coefficient of determination R^2 (0.96 and 0.92) and MAPE (4.9% and 8.9%, when the 3-day strength is not included) for mixture prepared with water-binder ratio of 0.52 and 0.67, respectively. (Note : the collected model parameters are a = 0.88, $ß$ = 0 θ = -20.71, m_1 = -4.03, m_2 = 17.25, n_1 = 1.23, n_2 = -0.78, x_1 = 121.7, x_2 = -136.7 and tabulated in Table 4).

Therefore, the prediction model for the compressive strength of self-consolidating waste LCD glass concrete reported in this study can accurately evaluate the compressive strength of concrete under different condition in the range of mixture ratios in this study. In addition, it may be used to predict the compressive strength of others glass concrete.

5. Conclusions

1. A compressive strength prediction model considering multiple variables of water-binder ratio, waste glass content and age simultaneously was constructed by combining the compressive strength characteristics of waste glass concrete based on a traditional hyperbolic model. According to the comparison analysis of the predicted values and the test results, the coefficient of determination R^2 was as high as 0.93 to 0.96, and the MAPE value was less than 10%. Thus, the designed compressive strength prediction model was accurate. The proposed model can provide

references for mix designs of adding waste LCD glass in concrete for future engineering applications.

2. This predicted model is also successful applied to calculate the compressive strength of washed glass sand concrete by Limbachiya in 2009. The coefficient of determination R^2 was ranged from 0.92 to 0.96 and the MAPE between 4.9% and 8.9%.

3. The compressive strength of specimen f_c' increased with the age but decreased as the water-binder ratio increased. Under the same mixture ratio, the compressive strength of specimen f_c' decreased as the waste glass content increased, which is consistent with previous studies. Whether the trend of test results of this study and the planned compressive strength prediction model are applicable to other mixing conditions should be further studied and validated.

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