Hindawi
Mathematical Problems in Engineering
Volume 2021, Article ID 6662238, 9 pages
https://doi.org/10.1155/2021/6662238

Research Article

Grey Prediction Model for Drying Shrinkage of Cement Concrete Made from Recycled Coarse Aggregate Containing Superabsorbent Polymers

Jinbao Zhang[1], **Song Li**[2], **and Jiahui Zhai**[3]

[1]*Qinghai Transportation Holding Group Co., Ltd., Xining 810001, China*
[2]*School of Transportation, Wuhan University of Technology, Wuhan 430070, China*
[3]*School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China*

Correspondence should be addressed to Jiahui Zhai; 2020261122@mail.nwpu.edu.cn

Received 19 December 2020; Revised 29 December 2020; Accepted 16 January 2021; Published 29 January 2021

Academic Editor: Bowen Guan

The aim of this paper is to investigate the effect of superabsorbent polymers (SAPs) on the drying shrinkage of the recycled concrete (RC). The natural aggregate (NA) was replaced by recycled aggregate at three replacement ratios (0%, 50%, and 100%). Then, the recycled concrete (RC) with different SAP contents was prepared. The performance of recycled concrete with different SAP content was analyzed with slump test, compressive strength test, and drying shrinkage test. GM (1, *N*) grey prediction model was utilized to predict the drying shrinkage of recycled concrete containing SAP. The results show that the strength and durability of concrete are decreased by the addition of recycled aggregate. With the increase of the dosage of SAP, the strength and durability also raise. The prediction GM (1, *N*) model for the drying shrinkage of recycled concrete with SAP is in good agreement with the actual drying shrinkage.

1. Introduction

Due to low cost, convenience, simple production process, and excellent mechanical and durability properties, natural concrete (NC) materials are widely utilized in building construction, road engineering, and bridge engineering [1–4]. With the rapid development of the economy, the huge demand for concrete materials is increasing. The cement concrete is composed of cement, aggregate, sand, and some admixtures. The main source of the coarse aggregate is crushed natural rocks obtained from natural mountains [5]. This has consumed the amount of natural rock of nonrenewable resources and caused the higher price of natural aggregates. On the other hand, according to the statistics of China, the production of concrete reached 1.8 billion tons in 2020, and construction waste such as waste concrete from the demolition of abandoned buildings was approximately 134×10^8 tons [6–8]. Meanwhile, the construction and demolition waste (CDW) in China has shown an increasing trend.

Many studies have shown that the utilization of recycled coarse aggregate to prepare cement concrete not only saves 60% natural aggregate resource but also consumes a large amount of CDW and reduces 20% emission of CO_2 [9, 10]. However, replacing natural aggregates with recycled aggregates will result in a decrease in the durability of concrete. Recycled aggregate is composed of natural aggregate and old mortar. There are a lot of pores in the old mortar and interfacial transition zone (ITZ). Therefore, RA showed higher porosity and water absorption compared with natural aggregate [11]. Concrete made of RA is easy to shrink and crack, resulting in the insufficient durability of concrete. Therefore, it is necessary to investigate the shrinkage of recycled concrete. The factor that affects shrinkage is complex, including wind speed, constituents, temperature, curing time, and pore size distribution [12]. The loss of water of the calcium silicate hydrates (CSHs) caused by a low relative humidity environment usually leads to the volume reduction of concrete. This phenomenon is called drying shrinkage [13]. The models that are widely utilized to predict shrinkage including the EC2-08 [14], ACI 209R [15], the Bažant-Baweja B3 [16], the CEB Model Code 99 [17], and the GL2000 [18] have been improved. Haejin et al. [19] investigated dry shrinkage of crushed returned concrete aggregate, evaluated the validity of the ACI 209 model, and found that the ACI 209 model is not suitable for the mixture that is beyond the standard conditions. Therefore, a new model was established to evaluate the drying shrinkage of the concrete made from the crushed returned concrete aggregate. Al-Manaseer et al. [20] estimated the shrinkage prediction capabilities of models based on the RILEM database [21, 22] and found that the Bažant-Baweja B3 and GL2000 models convey the best predictions for the shrinkage strain. Zhang et al. [23] proposed a prediction model for early-age shrinkage of cement paste considering the influence of wind speed. Li et al. [24] established some prediction equations by analyzing the relationship between pore structure and shrinkage of cement-based materials. Wang et al. [25] established a theoretical drying shrinkage model for RC considering the properties of the concrete, including its service time and strength. Compared with the empirical statistical regression method, autoregressive moving average model, and adaptive control Markov model, the grey model is more used due to the high prediction accuracy [26]. Wang et al. [27] used GM (1, 1) model to predict the drying shrinkage of crumb rubber concrete. Tang et al. [28] established the monthly attenuation prediction for asphalt pavement performance by using GM (1, 1) model. Shrinkage is one of the important factors that affect the durability of recycled concrete, which is closely related to time. However, there are few studies on the grey prediction model for shrinkage of concrete made from recycled aggregates.

The internal curing material maintains the relative humidity inside the concrete by releasing water, and it was used in cement concrete to solve the problem of shrinkage and cracking. As a highly effective internal curing material, superabsorbent polymers (SAPs) can significantly decrease the shrinkage of concrete. Kong et al. [29] analyzed the influence of presoaked SAP on the shrinkage of high-performance concrete (HPC) and found that the addition of SAP decreased the drying shrinkage of high-performance cement-based materials under the same water-cement ratio. Ma et al. gained a similar result.

In this study, NA is replaced by RA with 0%, 50%, and 100% replacement rates. Recycled aggregate concretes with 0.3%, 0.5%, and 0.7% SAP were prepared. The workability, mechanical properties, and shrinkage of concrete made from recycled coarse aggregate containing were analyzed, respectively. GM (1, N) grey prediction model was established to predict the drying shrinkage of recycled concrete with SAP.

2. Materials and Methods

2.1. Raw Materials. Ordinary Portland cement was utilized in this paper and its physical properties are shown in Table 1. Recycled coarse aggregate was used in the experiments with the grain size of 4.75–9.5 mm, 9.5–19 mm, and 19–31.5 mm. The physical properties of recycled coarse aggregate are shown in Table 2. River sand was used as fine aggregate, and its properties are shown in Table 3. Superplasticizer was supplied by Shandong Gaoqiang Co., Ltd., and its solid content was 37%. The performance of SAP is shown in Table 4.

2.2. Preparation of Recycled Concrete with SAP. The recycled aggregate was adopted by weight of natural aggregate at 0%, 50%, and 100%. The proportions of recycled concretes are shown in Table 5. The content of SAP is set as 0%, 0.3%, 0.5%, and 0.7% by mass of concrete.

2.3. GM (1, N) Grey Prediction Model. The grey theory is a kind of prediction method that can predict, make decision, or control using incompleteness of information. As the system is whitened by many effective messages around its forecast origin, the predicted series is fairly good.

Pairs of observations $\left\{x_1^{(0)}(1), x_1^{(0)}(2), \ldots, x_1^{(0)}(n)\right\}$ from a certain dynamic system with $n-1$ inputs $\left\{X_2^{(0)}, X_3^{(0)}, \ldots, X_n^{(0)}\right\}$ and an output $X_1{}^{(0)}$ are supposed to be available at an equispaced interval of time. Consider the original series, it can be obtained that

$$X_1^{(0)} = \left\{x_1^{(0)}(1), x_1^{(0)}(2), \ldots, x_1^{(0)}(n)\right\}, \tag{1}$$

$$X_2^{(0)} = \left\{x_2^{(0)}(1), x_2^{(0)}(2), \ldots, x_2^{(0)}(n)\right\}, \tag{2}$$

$$X_N^{(0)} = \left\{x_N^{(0)}(1), x_N^{(0)}(2), \ldots, x_N^{(0)}(n)\right\}. \tag{3}$$

$X_i^{(1)}$ are the 1-AGO series of $X_i^{(0)}$, $i = 1, 2, \ldots, N$, respectively. In addition, $Z_1^{(1)}$ is the adjacent generated serial of $X_1^{(1)}$, and then

$$x_1^{(0)}(k) + az_1^{(1)}(k) = \sum_{i=2}^{N} x_i^{(1)}(k) \tag{4}$$

is called the grey differential equation of GM (1, N) model, where 1 stands for the first-order derivative of 1-AGO series of $X_1{}^{(0)}$ (called the predicted series) and n stands for there being $n-1$ relative series (called the associated series) of the system.

Define $\widehat{\alpha} = \left[\, a \;\; b_2 \;\; \cdots \;\; b_N \,\right]^T$ as the parameter series of the grey differential equation of GM (1, N) model, and then according to the least square method (LSM), it can be obtained that

$$\widehat{\alpha} = \left(B^T B\right)^{-1} B^T Y, \tag{5}$$

where

$$B = \begin{bmatrix} -z_1^{(1)}(2) & x_2^{(1)}(2) & \cdots & x_N^{(1)}(2) \\ -z_1^{(1)}(3) & x_2^{(1)}(3) & \cdots & x_N^{(1)}(3) \\ \cdots & & \cdots & \\ -z_1^{(1)}(n) & x_2^{(1)}(n) & \cdots & x_N^{(1)}(n) \end{bmatrix}, \tag{6}$$

and

Table 1: Physical properties of cement.

Indicators	Fineness (%)	Setting time (min)		Volume stability (mm)	Compressive strength (MPa)		Flexural strength (MPa)	
		Initial setting	Final setting		3 d	28 d	3 d	28 d
Value	2.3	165	260	1.5	18.5	46.8	4.7	7.0

Table 2: Physical properties of recycled aggregate.

Grain size (mm)	Apparent relative density (kg/m^3)	Water absorption (%)	Flakiness and elongation (%)	Crushing value (%)	Dust content (%)	Impurity content (%)
4.75–9.5	2660	5.80	4.5	—	0.3	0.2
9.5–19	2636	4.41	4.3	24.5	0.2	0.4
19–31.5	2625	3.20	3.2	—	0.2	0.3

Table 3: Properties of fine aggregate.

Fineness modulus	Grade	Packing density (kg/m^3)	Apparent density (kg/m^3)	Voidage (%)	Powder content (%)	Content of soil (%)	Crushing value (%)
2.4	Medium sand	1447	2583	40	1.0	0.7	13

Table 4: Properties of superabsorbent polymers.

Water absorption rate	Deionized water absorption (g·g^{-1})	Tap water absorption (g·g^{-1})
600	≥600	≥300

Table 5: Mix proportions of recycled concretes.

	RA (%)	Cement (kg/m^3)	Water (kg/m^3)	Additional water consumption (kg/m^3)	Free water-cement ratio	Sand (kg/m^3)	Coarse aggregate (kg/m^3)	Addition agent (kg/m^3)
NC	0	367	180	0	0.49	735	1058	5.14
RC1	50	367	180	30.7	0.57	735	1058	5.14
RC2	100	367	180	61.4	0.65	735	1058	5.14

$$Y = \left[x_1^{(0)}(2) \;\; x_1^{(0)}(3) \;\; \cdots \;\; x_1^{(0)}(n) \right]^T. \tag{7}$$

Then

$$\frac{dx_1^{(1)}}{dt} + a x_1^{(1)} = b_2 x_2^{(1)} + b_3 x_3^{(1)} + \cdots + b_N x_N^{(1)} \tag{8}$$

is the albinism differential equation or silhouette equation of equation (4). From equation (8), the modeling value can be derived as

$$\begin{aligned} x_1^{(1)}(t) &= e^{-at}\left[\sum_{i=2}^{N}\int b_i x_i^{(1)}(t)e^{at}\mathrm{d}t + x_1^{(1)}(0) - \sum_{i=2}^{N}\int b_i x_i^{(1)}(0)\mathrm{d}t\right] \\ &= e^{-at}\left[x_1^{(1)}(0) - t\sum_{t=2}^{N} b_i x_i^{(1)}(0) + \sum_{i=2}^{N}\int b_i x_i^{(1)}(t)e^{at}\mathrm{d}t\right]. \end{aligned} \tag{9}$$

When the rangeability of $X_i^{(1)}$ $(i = 1, 2, ..., N)$ is small, the value of $\sum_{i=2}^{N} b_i x_i^{(1)}(k)$ can be deemed as a grey constant. Therefore, the approximate time response equation of equation (4) can be derived as

$$\hat{x}_1^{(1)}(k+1) = \left[x_1^{(1)}(0) - \frac{1}{a}\sum_{i=2}^{N} b_i x_i^{(1)}(k+1)\right]e^{-ak} + \frac{1}{a}\sum_{i=2}^{N} b_i x_i^{(1)}(k+1), \tag{10}$$

where $x_1^{(1)}(0)$ is equal to $x_1^{(0)}(1)$. Then

$$\hat{x}_1^{(0)}(k+1) = \hat{x}_1^{(1)}(k+1) - \hat{x}_1^{(1)}(k). \tag{11}$$

2.4. Test Procedure

2.4.1. Slump Test. Slump test was widely utilized to estimate the fluidity and working performance of concrete, and the operation was in accordance with specification (GB/T50081-2002, 2002; ASTM C143–C143M-15a, 2015).

2.4.2. Compressive Strength Test. According to the specification (GB/T50081-2002, 2002; ASTM C39/C39M-18, 2018a), the universal testing machine (UTM) was carried out to examine the compressive strength of 3 days, 7 days, and 28 days at the loading speed of 0.8 MPa/s.

2.4.3. Drying Shrinkage. The drying shrinkage samples of RC with 100 mm × 100 mm × 400 mm were prepared. After took away the model, the sample was stored in a dry room under the condition of 20°C and 50% relative humidity (RH). The change of length at 1, 3, 7, 14, 28, 56, and 90 days was estimated by shrinkage measuring instrument. Every type of concrete should be prepared as three samples, and the average value is reported as the results.

3. Results and Discussions

3.1. Slump of Concrete. The slump and expansion of fresh concrete are shown in Figure 1. When the SAP content is 0%, the slump and expansion of concretes decrease with the increase of the replacement proportion of RA. This is because the RA contained many inherent defects and microcracks and was covered by old mortar. The old mortar causes the increase of water absorption of RA and reduces the slump and expansion of recycled concrete. When the replacement proportion of RA is the same, the slump and extension of recycled aggregate increase with the increase of SAP dosage. A possible explanation for this might be that SAP is a microsphere, which can reduce the friction resistance among aggregates and improve the expansion and slump of the recycled concrete.

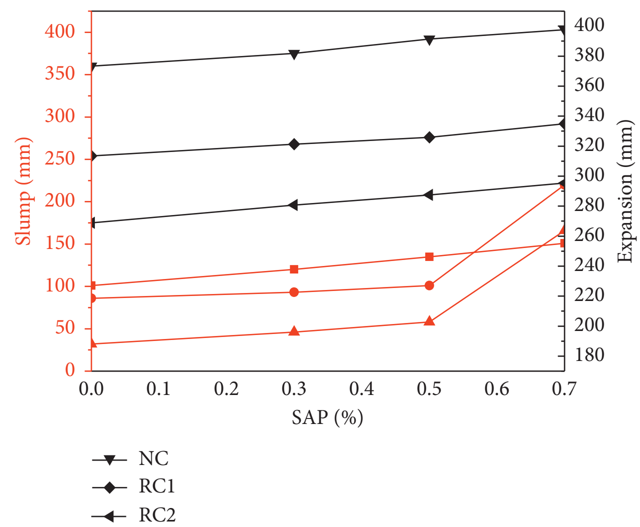

Figure 1: Influence of SAP on the workability of recycled concrete.

3.2. Compressive Strength. Figure 2 shows the influence of SAP on the compressive strength of recycled concrete. It can be seen that the compressive strength of concrete decreases with the increase of the replacement proportion of RA. When the replacement proportion of RA is 100%, the compressive strength (7 d and 28 d) of recycled concrete with SAP decreases. However, the reduction value of compressive strength of recycled concrete with SAP is smaller than that without SAP. This indicates that the addition of SAP can improve the mechanical properties of recycled concrete. Meanwhile, with the rise of SAP content, the compressive strength of recycled concrete becomes higher.

The RA contained many inherent defects and microcracks and was covered by old mortar, which leads to the decrease of modulus of elasticity. When added to recycled aggregate concrete, the SAP can reduce the amount of mixing water and the water-cement ratio. This is one reason that SAP can enhance the strength of concrete.

In addition, when the hydration process of cement consumes internal water of concrete, SAP will release the water that is absorbed to promote the hydration process of cement-based materials. Therefore, the hydration time of recycled concrete incorporation with SAP is longer than that without SAP, so its mechanical property is improved.

3.3. Shrinkage of Concrete. Figure 3 shows the effect of SAP content on the drying shrinkage of recycled concrete. It can be seen that the drying shrinkage of recycled concrete develops rapidly in the early stage and grows slowly in the later stage. With the rise of the replacement amount of RA, the drying shrinkage of concrete also raises. Under the condition of the same age and replacement amount of RA, the shrinkage rate of the recycled concrete with different dosages of SAP is lower than that without SAP, demonstrating that the addition of SAP can effectively reduce the drying shrinkage of the recycled concrete.

The higher water absorption of RA is the reason that causes the bigger drying shrinkage of recycled aggregate. To meet the workability of recycled concrete, more water will be added. However, the mixing water could not be completely consumed by the hydration process. After hardened, the evaporation of water will leave the pore and cause the shrinkage of concrete. The SAP acts as a "reservoir" in recycling concrete. After the water evaporation, the inside of the concrete is relatively dry, and SAP will release the water that is absorbed to promote the further hydration of cement-based material.

SAP continuously supplements the evaporated water of recycled concrete. This reduces the drying shrinkage of concrete and promotes the completion of hydration of concrete. The increase of hydration products can improve the density of concrete and reduce the drying shrinkage of concrete.

4. Prediction of Recycled Concrete Shrinkage Containing SAP Based on the Grey Prediction Model

The grey prediction model is mainly aimed at the processing of equidistant data. To obtain the data with equal spacing, the dry shrinkage rate (Y) is fitted linearly. However, due to the larger value of the dry shrinkage rate (Y), it is not convenient for calculation, so the dry shrinkage rate (Y) is normalized. Then the normalization interval is adjusted to a positive value, and the dry shrinkage (Y) that suffered the above process is finally used for grey prediction. Similarly,

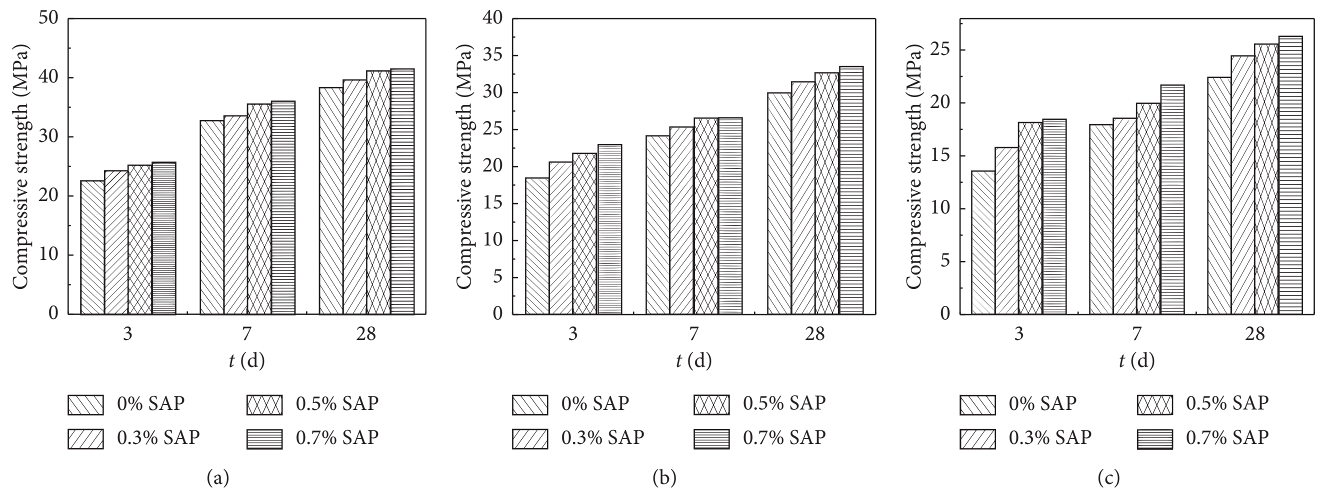

Figure 2: Influence of SAP on mechanical properties of reclaimed aggregate concrete. (a) 0% RA. (b) 50% RA. (c) 100% RA.

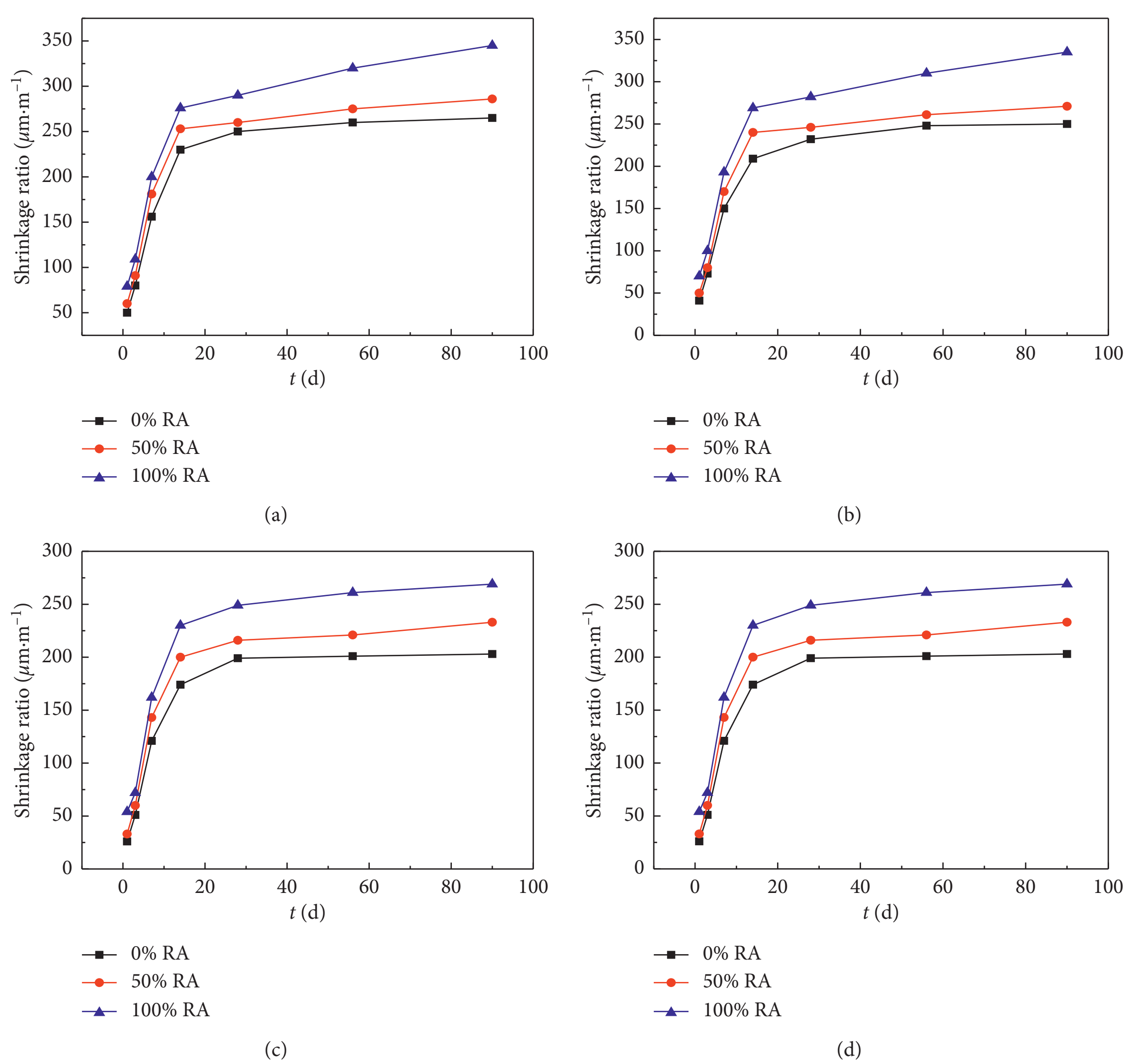

Figure 3: Influence of SAP content on drying shrinkage of recycled concrete. (a) 0% SAP, (b) 0.3% SAP, (c) 0.5% SAP, and (d) 0.7% SAP.

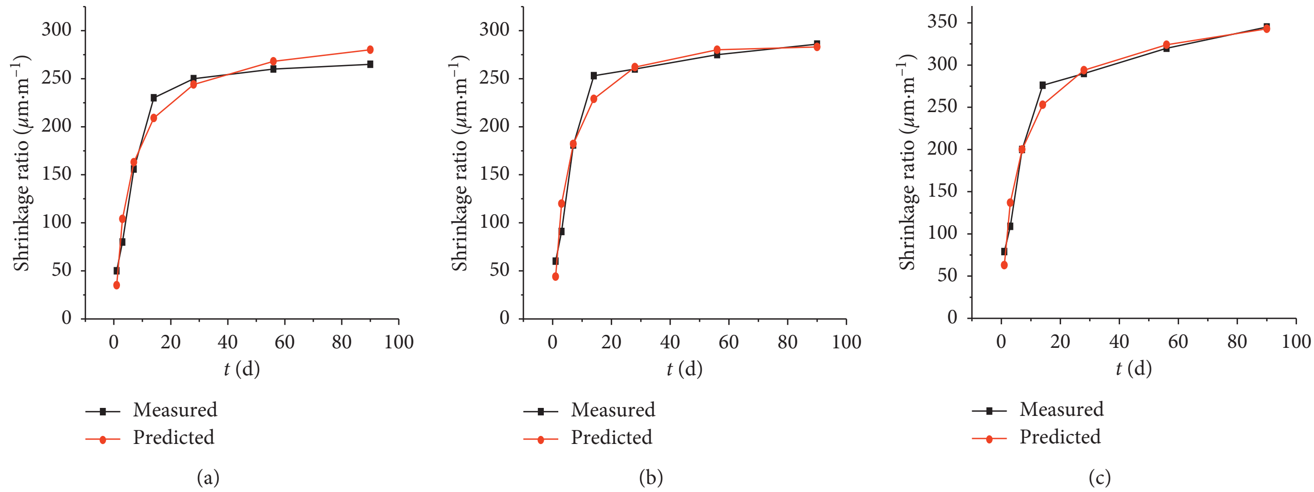

Figure 4: The test and predicted results of concrete shrinkage without SAP. (a) NC, (b) RC1, and (c) RC2.

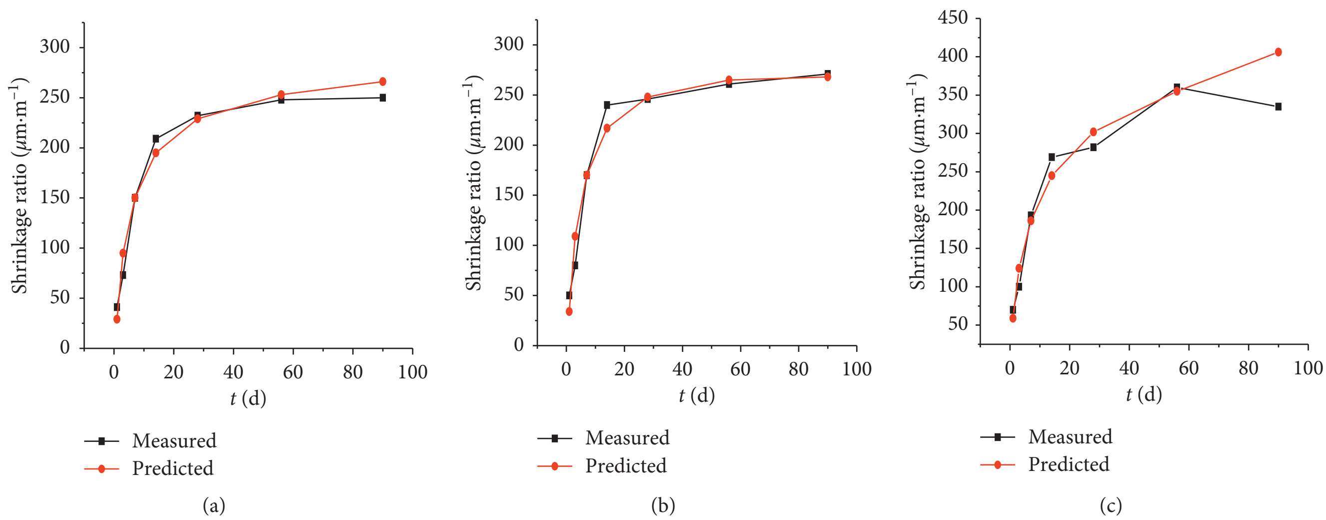

Figure 5: The test and predicted results of concrete shrinkage with 0.3%SAP. (a) NC, (b) RC1, and (c) RC2.

this operation is also performed for time (X) to obtain the time (X) that can be used in the grey prediction model. After the simulation, the predicted data can be inversely processed.

The shrinkage of recycled aggregate concrete containing SAP is predicted by the grey prediction model. 1, 3, 7, 14, 28, 56, and 90 d shrinkage results are used as the original data for the prediction. The results indicate that the maximum dry shrinkage occurs about 90 d.

Figures 4–7 show the test and predicted results of drying shrinkage. The results demonstrate that the 90 d shrinkage of RC decreases with the increase of SAP content. This indicates that the addition of SAP is beneficial to the durability of concrete.

The relative error, correlation, mean square deviation ratio, and probability of small error are usually used to evaluate the accuracy of the grey prediction model. In this study, the C is utilized to estimate the accuracy of the model and it can be calculated by equations (12)–(15):

$$\overline{x} = \frac{1}{n}\sum_{k=0}^{n} x(k), \tag{12}$$

$$S_1^2 = \frac{1}{n}\sum_{k=0}^{n} [x(k) - \overline{x}]^2, \tag{13}$$

$$S_2^2 = \frac{1}{n}\sum_{k=0}^{n} [\zeta(k) - \overline{\zeta}]^2, \tag{14}$$

$$C = \frac{S_2}{S_1}. \tag{15}$$

The elevated indicators of the accuracy of the grey prediction model are listed in Table 6.

The grade of (C)-mean square deviation ratio can be divided into four grades. All C values in this test are less than 0.1. According to Table 6, the grade is one, indicating the model owns best accuracy.

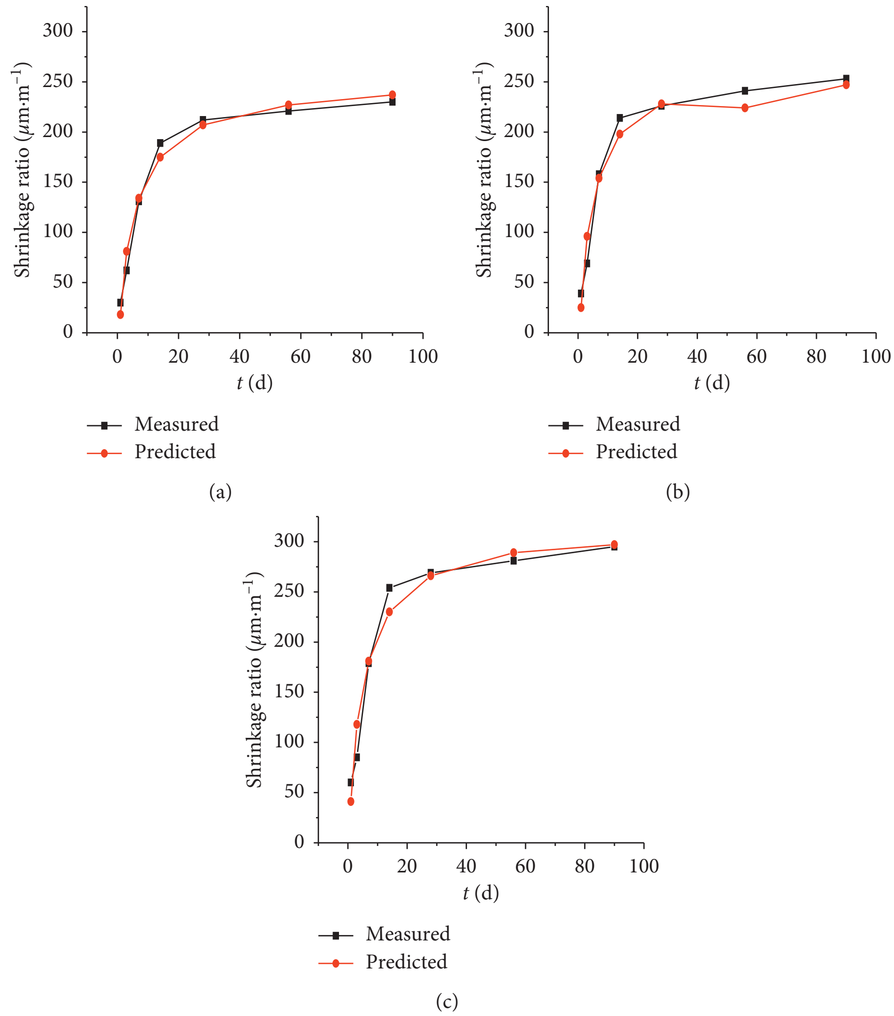

FIGURE 6: The test and predicted results of concrete shrinkage with 0.5% SAP. (a) NC, (b) RC1, and (c) RC2.

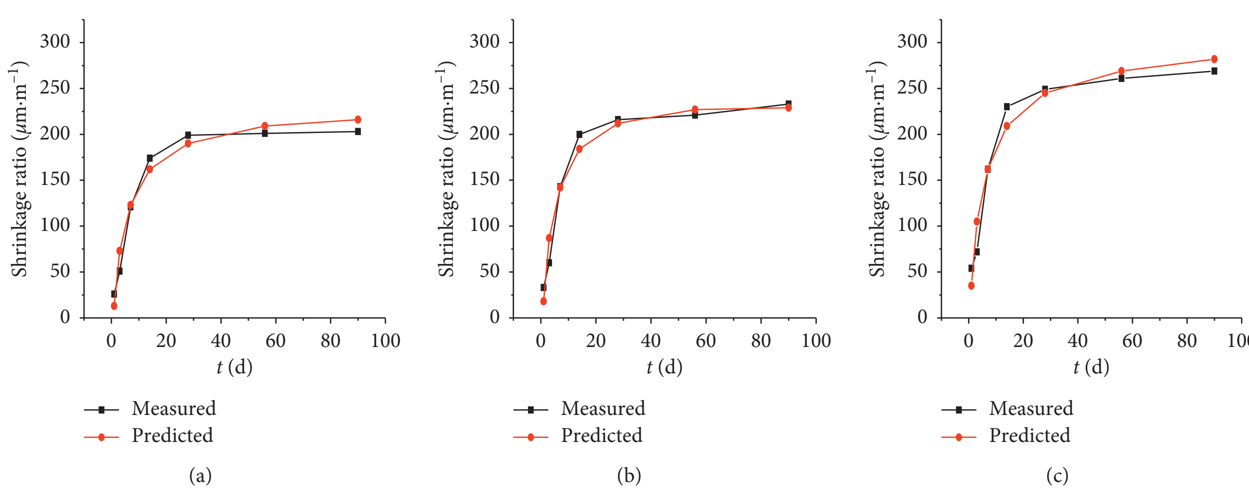

FIGURE 7: The test and predicted results of concrete shrinkage with 0.7% SAP. (a) NC, (b) RC1, and (c) RC2.

Table 6: The elevated indicators of the accuracy of the grey prediction model.

Grade	Indicators: Relative error	Correlation	(C)-mean square deviation ratio	Probability of small error
One	0.01	0.90	0.35	0.95
Two	0.05	0.80	0.50	0.80
Three	0.10	0.70	0.65	0.70
Four	0.20	0.60	0.80	0.60

5. Conclusions

In this paper, the natural aggregate (NA) was replaced by recycled aggregate at three replacement ratios (0%, 50%, and 100%). Then, the recycled concrete (RC) with different SAP contents was prepared. The performance of recycled concrete with different SAP contents was analyzed by slump test, compressive strength test, and drying shrinkage test. GM (1, N) grey prediction model was utilized to predict the drying shrinkage of recycled concrete containing SAP.

(1) The replacement of natural coarse aggregate with recycled aggregate has a negative influence on the workability, mechanical properties, and shrinkage of concrete.

(2) With the increase of the dosage of SAP, the strength and durability of recycled concrete also raise. The proper dosage of SAP is 0.7%.

(3) The prediction GM (1, N) model for the drying shrinkage of recycled concrete with SAP is in good agreement with the actual drying shrinkage. This indicates that the grey system theory is feasible to predict the drying shrinkage of recycled concrete with SAP.

(4) The GM prediction model provides a new and effective way of predicting the shrinkage of concrete. In addition, more factors such as the change of climate should be considered in this model in the future study.

Data Availability

The authors would like to declare that all the data in the manuscript were obtained by experiment and the data are true and effective in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by the Science and Technology Department Project of Qinghai Province (2021-QY-216) and Transportation Department Project of Qinghai Province (2019-14).

References

[1] S. Sun, X. Yu, B. Han, and J. Ou, "In situ growth of carbon nanotubes/carbon nanofibers on cement/mineral admixture particles: a review," *Construction and Building Materials*, vol. 49, pp. 835–840, 2013.

[2] Z. Li, S. Ding, X. Yu, B. Han, and J. Ou, "Multifunctional cementitious composites modified with nano titanium dioxide: a review," *Composites Part A: Applied Science and Manufacturing*, vol. 111, pp. 115–137, 2018.

[3] A. Nobili, L. Lanzoni, and A. M. Tarantino, "Experimental investigation and monitoring of a polypropylene-based fiber reinforced concrete road pavement," *Construction and Building Materials*, vol. 47, pp. 888–895, 2013.

[4] S. Freyne, C. Ramseyer, and J. Giebler, "High-performance concrete designed to enhance durability of bridge decks: Oklahoma experience," *Journal of Materials in Civil Engineering*, vol. 24, no. 7, pp. 933–936, 2012.

[5] Y. Jiao, Y. Zhang, M. Guo, L. Zhang, H. Ning, and S. Liu, "Mechanical and fracture properties of ultra-high performance concrete (UHPC) containing waste glass sand as partial replacement material," *Journal of Cleaner Production*, vol. 277, Article ID 123501, 2020.

[6] H. Duan, T. R. Miller, G. Liu, and V. W. Y. Tam, "Construction debris becomes growing concern of growing cities," *Waste Management*, vol. 83, pp. 1–5, 2019.

[7] J. De Brito and N. Saikia, *Recycled Aggregate in Concrete Use of Industrial, Construction and Demolition Waste*, Springer, Berlin, Germany, 2013.

[8] J. Xie, J. Li, Z. Lu et al., "Combination effects of rubber and silica fume on the fracture behaviour of steel-fibre recycled aggregate concrete," *Construction and Building Materials*, vol. 203, pp. 164–173, 2019.

[9] J. Sainz-Aja, J. Pombo, D. Tholken et al., "Dynamic calibration of slab track models for railway applications using full-scale testing," *Computers & Structures*, vol. 228, Article ID 106180, 2020.

[10] J. A. Sainz-Aja, I. A. Carrascal, J. A. Polanco et al., "Determination of the optimum amount of superplasticizer additive for self-compacting concrete," *Applied Sciences*, vol. 10, no. 9, p. 3096, 2020.

[11] C. Carloni and K. V. Subramaniam, "Investigation of subcritical fatigue crack growth in FRP/concrete cohesive interface using digital image analysis," *Composites Part B: Engineering*, vol. 51, pp. 35–43, 2013.

[12] V. W. Y. Tam and C. M. Tam, "Assessment of durability of recycled aggregate concrete produced by two-stage mixing approach," *Journal of Materials Science*, vol. 42, no. 10, pp. 3592–3602, 2007.

[13] A. M. Neville and J. J. Brooks, *Concrete Technology*, Pearson, London, United Kingdom, 2nd edition, 2010.

[14] EN-1992-1-1, *Eurocode 2–Design of Concrete Structures*, Comité Européen De Normalisation (CEN), Brussels, Belgium, 2008.

[15] ACI-209, *Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete*, Vol. 48, American Concrete Institute, Farmington Hills, MI, USA, 2008.

[16] Z. P. Bažant and S. Baweja, "Creep and shrinkage prediction model for analysis and design of concrete structures–model B3," *Materials and Structure*, vol. 28, no. 6, pp. 357–365, 1995.

[17] CEB-FIP, *Model Code for Concrete Structures*, Comité Euro-International Du Béton, Lausanne, Switzerland, 1990.

[18] N. J. Gardner and M. J. Lockman, "Design provisions for drying shrinkage and creep of normal-strength concrete," *ACI Materials Journal*, vol. 98, no. 2, pp. 159–167, 2001.

[19] H. Kim and D. G. Goulias, "Shrinkage behavior of sustainable concrete with crushed returned concrete aggregate," *Journal of Materials in Civil Engineering*, vol. 27, no. 7, Article ID 04014204, 2015.

[20] A. Al-Manaseer and J. P. Lam, "Statistical evaluation of shrinkage and creep models," *ACI Materials Journal*, vol. 102, no. 3, pp. 170–176, 2005.

[21] RILEM-TC-107, "Guidelines for characterizing concrete creep and shrinkage in structural design codes or recommendations," *Materials and Structure*, vol. 28, no. 1, pp. 52–55, 1995.

[22] Z. P. Bažant and G. H. Li, "Comprehensive database on concrete creep and shrinkage," *ACI Materials Journal*, vol. 105, pp. 635–637, 2008.

[23] L. Zhang, X. Qian, J. Lai, K. Qian, and M. Fang, "Effect of different wind speeds and sealed curing time on early-age shrinkage of cement paste," *Construction and Building Materials*, vol. 255, Article ID 119366, 2020.

[24] Y. Li, J. Bao, and Y. Guo, "The relationship between autogenous shrinkage and pore structure of cement paste with mineral admixtures," *Construction and Building Materials*, vol. 24, no. 10, pp. 1855–1860, 2010.

[25] Y. Liu, T. Tafsirojjaman, A. U. R. Dogar, and A. Hückler, "Shrinkage behavior enhancement of infra-lightweight concrete through FRP grid reinforcement and development of their shrinkage prediction models," *Construction and Building Materials*, vol. 258, Article ID 119649, 2020.

[26] J. Ofosu-Adarkwa, N. Xie, and S. A. Javed, "Forecasting CO2 emissions of China's cement industry using a hybrid Verhulst-GM (1, *N*) model and emissions' technical conversion," *Renewable and Sustainable Energy Reviews*, vol. 130, Article ID 109945, 2020.

[27] M. Wang, X. M. Sui, Z. X. Han, and Y. Li, "Grey prediction of drying shrinkage of crumb rubber concrete based on GM (1, 1)," *Journal of Building Materials*, vol. 6, pp. 653–656, 2008.

[28] L. M. Tang and D. Y. Xiao, "Monthly attenuation prediction for asphalt pavement performance by using GM (1, 1) model," *Advances in Civil Engineering*, vol. 2019, Article ID 9274653, , 2019.

[29] X.-M. Kong, Z.-L. Zhang, and Z.-C. Lu, "Effect of pre-soaked superabsorbent polymer on shrinkage of high-strength concrete," *Materials and Structures*, vol. 48, no. 9, pp. 2741–2758, 2014.