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Prediction of different concrete carbon emissions based on particle swarm optimization

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Abstract

Building energy consumption in modern society is huge, accounting for about 1/3 of the total energy consumption in society. Concrete is an important material in the construction industry, and its green transformation is of great significance to the realization of "carbon peak" and "carbon neutrality". Starting from two paths, this paper combines particle swarm optimization algorithm and least square method to predict the carbon emissions of ordinary concrete and recycled aggregate concrete in the construction industry in the next five years, and conduct a comparative analysis.

Keywords

PSO,LCA, Recycled aggregate, carbon emission, forecast.

1. Introduction

The progress of science and technology is bound to be accompanied by the consumption of energy. With the rapid development of society and the rapid consumption of energy, the problem of carbon emissions cannot be ignored. "Energy saving and emission reduction" has become the main theme of the times. my country has proposed the general goal of "carbon peak" in 2030 and "carbon neutrality" in 2060. Concrete is an important material in the construction industry, and studying its carbon reduction performance has long-term significance for the future carbon emission consumption of the construction industry.

2. Forecast of future concrete consumption

In view of the fact that it is difficult to inquire about the national consumption data of concrete, the data of the national building area in the past ten years is easy to obtain, and historical experience data shows that the concrete consumption per unit building area can be roughly set at 0.35m3. Therefore, this article uses a certain conversion ratio and multiplies the building area by the corresponding ratio coefficient to obtain the national concrete consumption data in the past ten years as shown in the figure below, which provides data support for the future carbon emission forecast of concrete.

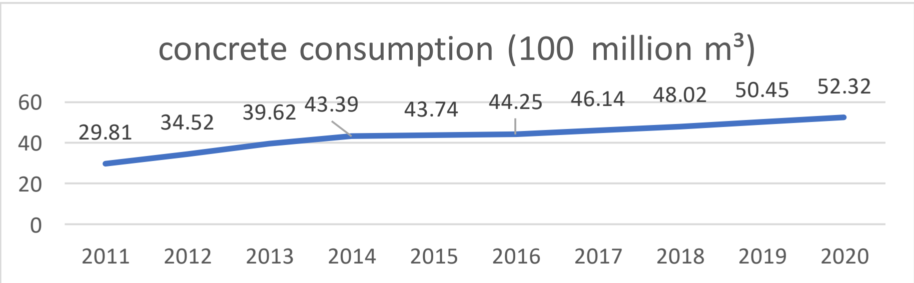

chart 1 the future carbon emission forecast of concrete

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First, use the Pearson correlation coefficient to determine whether there is a linear relationship. Here we use SPSS to perform data analysis to achieve:

Correlation

		Year	concrete consumption ($10000m^3$)
Year	Pearson correlation	1	.961**
	Sig.（Double tail）		.000
	Number of cases	10	10
Concrete consumption ($10000m^3$)	Pearson correlation	.961**	1
	Sig.（Double tail）	.000	
	Number of cases	10	10

**. At 0.01 level (two-tailed), the correlation is significant.

chart 2 Pearson correlation coefficient

The analysis results show that the significance value is 0.000<0.05, and the correlation value is 0.961. Since the value is 0.961>0.6, it shows that there is a correlation. Two * is displayed above the data, indicating that the correlation is strong. The results of this data indicate that the correlation between the two data at the 0.01 level is significant (if a * is displayed, the correlation between the data is significant at the 0.05 level).

Significance value is the prerequisite for correlation. Obviously, there is a strong positive correlation between year and concrete consumption. Therefore, we can use the least square method to obtain the linear regression equation as:

$$y = 22064.5912x - 44038911.2866 \tag{1}$$

The result of the least squares method prediction is a linear relationship between the two variables, while the real data obviously shows a non-linear relationship, so the chi-square goodness-of-fit test is used below to evaluate the degree of fit:

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y}_i)^2} \tag{2}$$

The degree of fit is calculated by the above formula: $R^2 = 0.92$

The closer the R^2's value is to 1, the better the fit of the regression line to the observed value; conversely, the smaller the value, the worse the fit of the regression line to the observed value. In the above example, the R^2's value is relatively close to 1, indicating that the collected data has a high degree of linearity and can provide data support

for the following carbon emission predictions.

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In summary, we can get the forecast value of concrete consumption（100 million m3） from 2011 to 2025 as shown in the figure below:

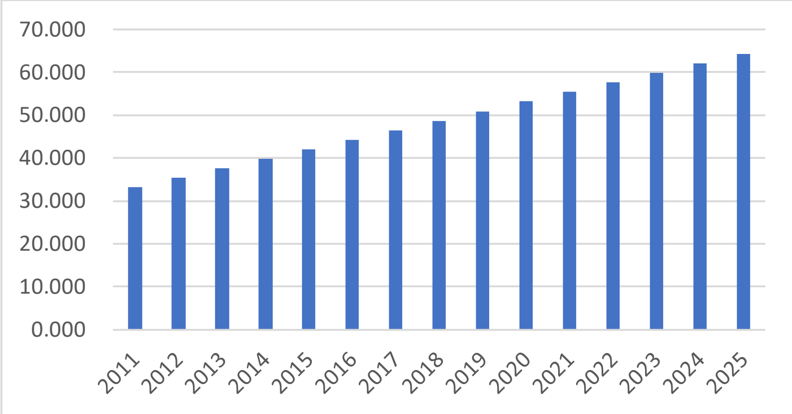

chart 3 the forecast value of concrete consumption

3. Carbon emission forecast based on actual data

Based on the specific cases of Taiyuan City and Shanghai in the literature [3], [4], through scholars' conversion of recycled aggregate concrete to actual concrete usage, we can sort out the actual carbon emissions per unit of ordinary concrete and recycled aggregate concrete. data.

3.1. Ordinary concrete

	Case 1	Case 2	Case 3
Place	Beihan Village, Taiyuan City	Taiyuan City Center	Shanghai
Building Type	Four-layer frame structure	High-rise residential commercial building	A ready-mixed concrete station
Carbon emissions per unit of concrete（kg/m3）	256.7737251	317.3174988	250.861

chart 4 Examples of carbon emissions per unit of concrete

Integrating the carbon emissions per unit of concrete for three different building types, we might as well take the average of them to expect to get a general result per unit of ordinary concrete carbon emissions (kg/m3).which is:

$$RE_1 = 274.984074652858$$

Combined with the forecast of future concrete consumption in the previous section, we can get the forecast value of total carbon emissions if we choose to use ordinary concrete in the futureCO2(11)：

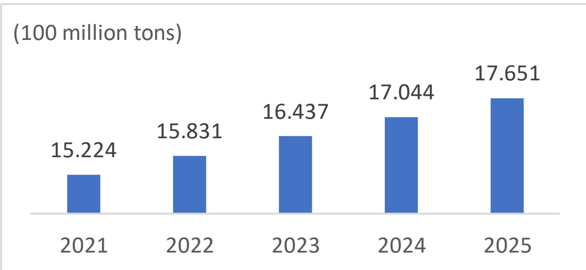

chart 5 the forecast value of total carbon emissions of ordinary concrete

3.2. Recycled concrete

	Case 1	Case 2	Case 3
Place	Beihan Village, Taiyuan City	Taiyuan City Center	Shanghai
Building Type	Four-layer frame structure	High-rise residential commercial building	A ready-mixed concrete station
Carbon emissions per unit of concrete （kg/m3）	286.3001543	339.0166914	171.568

chart 6 Examples of carbon emissions per unit of concrete

Integrating the carbon emissions per unit of concrete for three different building types, we might as well take the average of them to expect to get a general result per unit of recycled aggregate concrete carbon emissions (kg/m3).

which is:

$$RE_2 = 265.628281910034$$

Similarly, combined with the forecast of future concrete consumption in the previous section, we can get the forecast value of total carbon emissions if we choose to use recycled aggregate concrete in the futureCO_2(12)：

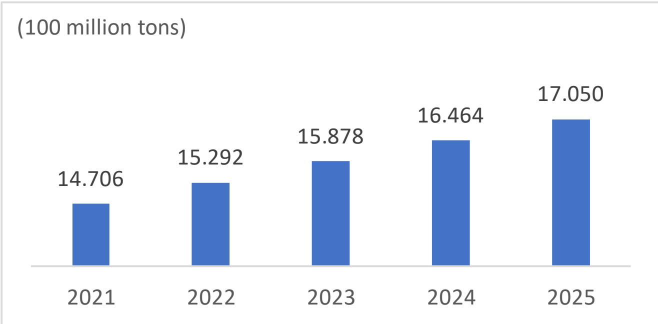

chart 7 the forecast value of total carbon emissions of recycled aggregate concrete

4. Carbon emission forecast based on LCA

4.1. Overview of the basic situation of concrete carbon emissions

Concrete is mainly composed of cement, water and coarse and fine aggregates. For ordinary concrete and recycled aggregate concrete with the same strength cement and water-cement ratio, the difference in carbon emissions at the production stage mainly comes from aggregates, that is, the use of natural aggregates or recycled aggregates. However, the difference in other stages is not big. The following is to predict the carbon emission of different types of concrete materials in each stage during the full life cycle of concrete, in order to obtain the carbon emission of different types of concrete per unit.

4.2. Carbon emission model at each stage

4.2.1. Raw material production stage

Based on the CO_2 equivalent emissions of each raw material production stage obtained through on-site technical investigations and comprehensive multiple literature regional life cycle inventory (LCI) in literature [1], we can obtain the carbon emission factor of each unit of raw material E_i (kg/t) As shown in the following table:

Raw materials	water	cement	sand	RP	NCA	RCA	Water reducing agent
E_i	0.347	950.68	4.367	48.8	8.772	12.882	29.168

chart 8 the carbon emission factor

$$C1j = \sum_{i=1}^{7} \left(E_i \times m_{ij}\right) \tag{3}$$

In the formula, m_{ij} represents the unit consumption of the i-th raw material of the j-th concrete. E_i represents the carbon emission factor of the i-th raw material, C1jIndicates the carbon emissions during the production stage of raw materials (j=1 means ordinary concrete, j=2 means recycled aggregate concrete). Therefore, the carbon emissions per unit of concrete raw material production stage can be predicted by formula (3).

4.2.2. Material transportation stage

Since it is difficult to calculate the total carbon emissions during the transportation phase of building materials, the transportation distance method is generally used in the industry to calculate the carbon emissions during the transportation phase. The transportation of materials in the construction industry can be divided into water transportation and land transportation. We may wish to use these two as the basis for calculation to obtain a carbon emission forecast model for the material transportation stage. By querying the historical data of the concrete mixing plant, the energy consumption of the two modes of transportation and the effective carbon emission factor of the fuel are obtained as shown in the following table:

Mode of transport	**Transportation energy consumption/MJ(t·km)$^{-1}$**	**Effective CO2 emission factor of fuel/kg·(MJ)$^{-1}$**
Land transportation	2.055	0.074
water transport	0.468	0.074

chart 9 Effective carbon emission factor

Assume that the transportation distance of each raw material is X_i, S_k Represents the transportation energy consumption of the k-th transportation mode, B_k represents the effective carbon emission factor of the fuel of the k-th transportation mode, then the carbon emission per unit mass of raw material transportation U_i（kg· t^{-1}）Can be obtained by the following formula:

$$U_i = \sum_{k=1}^{2} \left(S_k \times X_i\right) \cdot B_k \tag{4}$$

Carbon emissions from the transportation of raw materials per unit mass U_i, We can further obtain the carbon emissions per unit of concrete raw material transportation stage :

$$C_{2j} = \sum_{i=1}^{7} U_i \cdot m_{ij} \tag{5}$$

In the formula, m_{ij} Indicates the unit consumption of the i-th raw material of the j-th concrete, C_{2j} Indicates the amount of carbon emissions per unit of concrete raw material transportation stage.

4.2.3. Construction stage

Energy consumption at this stage is mainly for coal, electricity and oil consumption. The rest of the energy consumption accounts for a minority and is ignored here. Therefore, it is good to use these three items as carbon emission factors to calculate and predict the carbon emission during the concrete production and construction stage. It can be known from the statistical data of relevant international or Chinese units:electricity0.92kg/kw.h、Fuel oil2.98kg/L、Burning coal2.76kg/kg。

$$C3j = \sum_{n=1}^{3}\sum_{i=1}^{7} \mathrm{B_n P}_{in} \times m_{ij} \quad (6)$$

In the formula, m_{ij} Indicates the unit consumption of the i-th raw material of the j-th concrete,P_{in} represents the consumption of the n-th energy of the i-th raw material,$\mathrm{B_n}$ the carbon emission factor of the n-th energy representing the i-th raw material. $C3j$ Indicates the amount of carbon emissions during the concrete construction phase.

4.2.4. Demolition stage

Because the energy consumption of the demolition process is difficult to calculate in detail, some domestic scholars have proposed that the energy consumption of demolition can be estimated at 90% of the energy consumption of concrete construction and installation to estimate the carbon emissions during the concrete demolition stage $C4j$:

$$C4j = 90\% \times C3j \quad (7)$$

4.3. Future concrete carbon emissions forecast

Combining the carbon emission prediction models of each stage calculated by the preceding sub-items, we can obtain the unit carbon emission models of the two types of concrete, and then integrate the future concrete consumption prediction model established in the first section$Q$,We can get the future concrete carbon emission model as follows:

$$CE_j = Q \times \sum_{\mathrm{i}=1}^{4} \mathrm{C_{ij}} \quad (8)$$

Where j=1 means ordinary concrete, j=2 means recycled aggregate concrete.

By searching for relevant information, we weighted it according to the frequency of use of each strength grade of concrete to obtain the unit consumption of two different types of concrete, as shown in the following figure:

Raw materials Concrete type	NC/kg	RAC/kg
water	160	173.5
cement	320	282
sand	793	768
RP	0	50
NCA	1030	540
RCA	0	540
Superplasticizer	1.28	1.992

chart 10 Unit consumption of raw materials

Through the above formula, we can get the general results of different types of carbon emissions per unit of ordinary concreteCE_j:

CE_1	CE_2
289.44	255.67

chart 11 Carbon emissions per unit of ordinary concrete

Combined with the prediction of future concrete consumption in the previous section, we can get the predicted value of total carbon emission CO2 if we choose to use ordinary concrete in the future (21) and the predicted value of total carbon emission CO2 if we choose to use recycled aggregate concrete. (twenty two) :

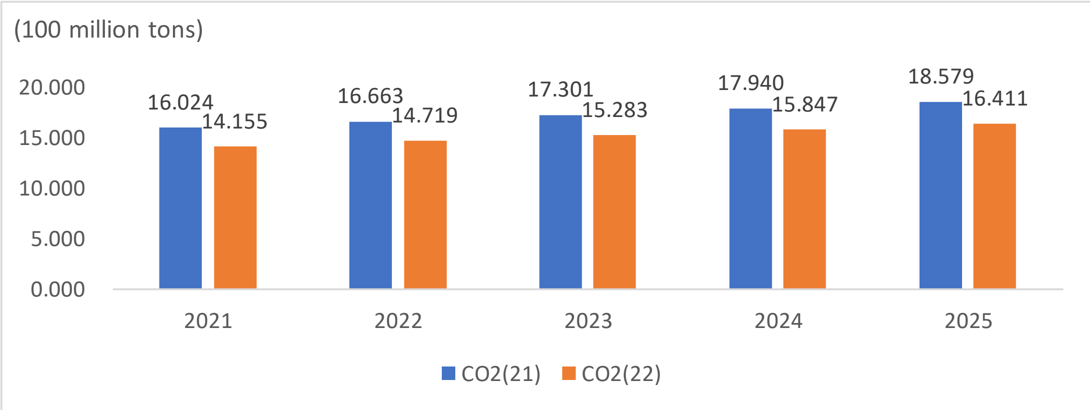

chart 12 Carbon emissions forecast

5. Model fit comparison analysis

Usually the least squares method tends to fall into the situation of local optimal solution, so in the parameter fitting part, modern optimization algorithms are usually used for optimization. In view of the better convergence of the particle swarm algorithm, it is simple and easy to implement, this paper uses the particle swarm optimization algorithm to fit the two concrete prediction data separately, hoping to get more accurate prediction results.

We first check the number of iterations through MATLAB, set the maximum number of iterations Tmax=600, the maximum particle speed is 15, the particle swarm size is 70, and finally the optimal number of historical iterations is obtained as shown below:

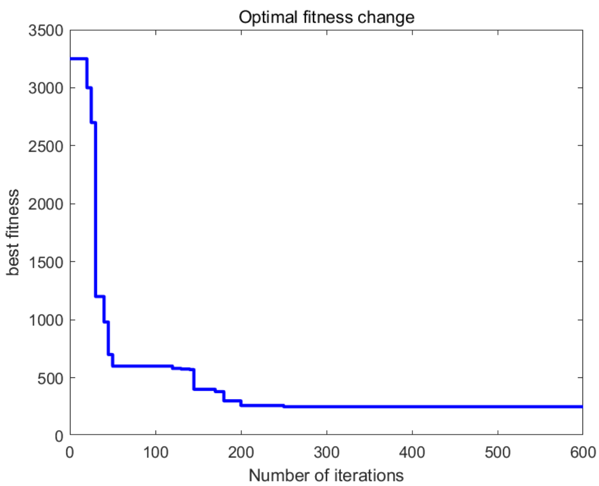

chart 13 the optimal number of historical iterations

It can be seen from the above figure that it stabilizes after about 250 iterations. On this basis, we use the linearly decreasing inertia weight proposed by Shi.Y, and make better use of the particle swarm algorithm to obtain the optimal solution.

We will draw the three final prediction results through matlab and show them together in the following figure (the left picture is the carbon emission prediction of ordinary concrete, and the right picture is the carbon emission prediction of recycled aggregate coagulation).

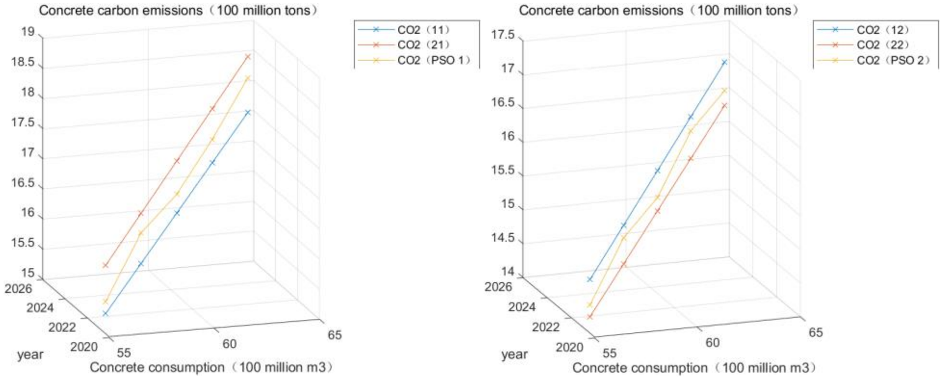

chart 14 Comparison and summary of carbon emission forecasts

6. Conclusion

From the comparison of the two figures, it can be seen that the carbon emission of the future choice of recycled aggregate concrete is lower than the use of traditional ordinary concrete, which is conducive to my country's carbon reduction action. The carbon emission of recycled concrete is lower than that of ordinary traditional concrete, showing a larger green space.

Advocating the use of recycled aggregate concrete is not only conducive to the recycling of "urban mines", but also contributes to the creation of a green and harmonious ecological environment, which will also become an opportunity to solve the city's high carbon emissions.

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