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Research on the Application of New Energy and Low-carbon Technologies in the Repair of Concrete Surface Defects

Yanxia Li[1]

[1] Changzhou Vocational Institute of Engineering
Changzhou, Jiangsu(China)
E-mail: 13584356704@163.com

Abstract. Photovoltaic heating is a new energy technology, which plays an obvious role in concrete curing, which can shorten the curing time of concrete. However, the role of this technology in concrete surface repair is not clear. In order to expand the application scope of low-carbon energy, this paper takes concrete surface repair as the research object and conducts photovoltaic heating analysis. Firstly, the data of concrete surface depression were collected, and then the repair effect of photovoltaic heating technology on the concrete surface was analyzed with C30 # as the research object, such as compressive strength, curing time, complex spacing, repair cost and energy consumption. and analyze the range of variation of each indicator; The results show that the photovoltaic heating technology can shorten the curing time by 20% and improve the compressive strength to 50kg/m2 with a complex spacing of less than 20 microns. At the same time, the repair cost and energy consumption are reduced, and the reduction range is 15~18%. Therefore, new energy and low-carbon technologies such as photovoltaic heating can effectively repair concrete surface defects, build on the cost and energy consumption of repair, improve the repair time, and meet the overall requirements of concrete construction.

Key words. Low-carbon Energy, Photovoltaic Heating, Concrete, Surface Defects, Repair.

1. Introduction

Concrete is prone to surface defects due to subjective or objective reasons during construction, so it is necessary to repair it later. However, the repair of surface defects has the problem of poor integration, and the adhesion between concrete is relatively weak [1], [2]. Therefore, it is necessary to carry out comprehensive maintenance of temperature and humidity to enhance the strength of concrete. At present, the subjective empirical observation of concrete surface repair is mainly used, and the results vary greatly, especially in terms of compressive strength and the adhesion of complexes [3], [4]. When reconstructing concrete surfaces, the temperature of the pore water must be very different from the background temperature of the seepage channel. However, the thermal pulse method successfully solves this problem with the gradient method. If a fully heated optical fiber is used as the heat source, it is difficult to ensure the durability of the thermal energy due to the uneven distribution of resistance in the heating section. This can negatively impact the accuracy of defect detection. In addition, the heating time of the entire process is quite long, which requires a large heating capacity. In view of the above problems, some scholars have proposed a heating curing method, but this method has problems such as short heating time and unconstant temperature, which makes it unable to be effectively applied. Some scholars have also proposed a new energy continuous heating method, which heats concrete at low temperature, so as to maintain its temperature and humidity and enhance the viscosity between concrete complexes. However, there is some controversy about this method, mainly because of the lack of cases to support its implementation effect. At the same time, the obvious difference between the temperature environment around the defect path and the normal defect condition is observed when the defect event occurs. Moreover, in the case of the thermal pulse method, heat treatment of the optical fiber is required. Due to the transfer of heat energy caused by the defect, part of the heat energy is dissipated. Some scholars also believe that in the process of concrete surface repair, heating can be carried out in the form of light to maintain the humidity of the concrete itself [5], [6], especially the humidity between the pores, to improve the curing effect during the period, so theoretically, heating can promote the complex strength between concrete complexes and form solidified fibers. In this paper, we first collect the data on concrete surface repair defects, including the degree of defects, the angle of defects, and the volume of defects, etc., and classify and compare them. Then, photovoltaic heating technology was used to repair the fixed line of concrete, and the temperature and humidity during the curing process were measured, and the complexes were observed by electron microscopy. Finally, by comparing the advantages and disadvantages of photovoltaic heating technology and manual maintenance technology, as well as the differences in strength, cost and low energy consumption, the effect of photovoltaic heating technology on concrete restoration construction is obtained, and the purpose of the research is to expand the development of new energy technologies such as photovoltaic heating and reduce the low carbon emission and cost of concrete surface repair.

2. Problem Description of Low-carbon New Energy Technology and Concrete Surface Defect Repair

A. Concrete Surface Defect Repair

Concrete surface defects are mainly caused by cavities, bubbles, and cracks, so it is necessary to analyze them, such as testing the deterioration of the cavity surface, and on this basis, conduct an in-depth analysis of its strength, and measure the area of its defects. Hypothesis 1: The type of surface defect is x_i, the time of existence of the defect T_θ is, and the mass cycle of the concrete is T, then the surface defect $\frac{dQ}{dt}$ can be expressed as:

$$\frac{dQ}{dt} = x_i \cdot h_i \cdot (T - T_\theta) \tag{1}$$

Among them, h_i is the environment in which the concrete is located, such as the humidity and temperature of the air. The strength of the defect is determined by measuring the temperature, as well as the acidity and alkalinity that occur in the porous medium [7], [8]. The relationship between the repair location and the original concrete can be expressed as:

$$dQ = c_i \cdot m_i + \Delta T \tag{2}$$

where the dQ concrete representing the repair location m_i represents the repaired concrete, the repair c_i parameters.

By substituting equation (2) into equation (1), the differential equation for temperature T and time T can be obtained. Based on this equation, the study can calculate: Due to the difference in hardness and strength between concrete, the strength test of the repaired concrete assumes that its strength is e^t and the repair time is $T_0 - T$, then the amplitude before the repaired concrete is

$$T \cdot m_i = (T_0 - T) \cdot e^t + T_\theta \tag{3}$$

In order to better observe the strength of concrete, it is necessary to shorten the difference between the concrete surface repair and the original repair $\lg(e \cdot m_i)$ and identify the variation range of the difference, so as to prove the relationship between the strength of concrete after repair.

$$\lg(e \cdot m_i) = \lg\left(\frac{T - T_\theta}{T_0 - T_\theta}\right) \tag{4}$$

Among them, ζ the interference factors of concrete are represented, and the specific calculation is as follows.

$$\zeta = \lg\left(\frac{T - T_\theta}{T_0 - T_\theta}\right) \cdot m_i' \tag{5}$$

In the temperature range of -40 °C~120 °C, the strength of concrete shows many changes, so the difference in its change should be recorded, as follows:

$$\lambda = K_T \cdot x_i \cdot m_i \left|\Delta T + \eta\right. \tag{6}$$

In the formula, the K_T sensitivity of concrete changes is represented. During the concrete defect repair process, it will be K_T set at approximately 10 pm/°C. At the same time, the interference coefficients of humidity and temperature are introduced η to improve the accuracy of the analysis process. Concrete surface defect repair after temperature disturbance can be expressed as:

$$\frac{dQ}{dt} = m_i \cdot \lg\left(\frac{\lambda\text{-}\lambda_\theta}{\lambda_0\text{-}\lambda_\theta}\right) \tag{7}$$

where the λ_θ input wavelength after concrete repair is denoted and the λ_0 output wavelength after concrete repair is described. From the research results, it can be known that the wavelength of concrete changes [9], [10] before repairing the input and output, and the degree of change of the length presents a linear angular relationship, so it is necessary to constrain its wavelength functionally, which can be constrained in the form of sinusoidal angle, as follows.

$$\lg\left(\frac{\lambda\text{-}\lambda_\theta}{\lambda_0\text{-}\lambda_\theta}\right) = \sin\Delta\lambda \cdot \lg\left(\frac{\lambda\text{-}\lambda_\theta}{\lambda_0\text{-}\lambda_\theta}\right) \tag{8}$$

B. Description of the Facilitating Effect of Photovoltaic Heating

The effect of photovoltaic heating on concrete surface repair is mainly divided into several aspects, which are as follows:

Calculate the photovoltaic heating information of concrete at different times, use it as a $x_1', x_2', x_3', \cdots\cdots, x_N'$ representation, and then calculate the heating difference coefficient of the concrete k to obtain the average strength information after heating x_{new}, which is calculated as follows.

$$x_{\text{new}} = x_i + rand(0,1) \cdot (x_j' - x_i) \tag{9}$$

where: $rand(0,1)$ is $(0,1)$ a random number in the interval, representing the change in the strength of the concrete. Then, the second-order Taylor calculation is performed on the difference after the repair of the concrete, and the photovoltaic energy consumption function is incorporated into $O_{\text{b}j}(\varphi)$ Eq. (10).

$$O_{\text{b}j}(\varphi) = \sum_{i=1}^{n} l(y_i, \hat{y}_i) + \sum_{i=1}^{t} \Omega(f_t) \tag{10}$$

where: $l(y_i, \hat{y}_i)$ is the carbon dioxide emissions; y_i is the heating temperature; $\hat{y}_i$ is the curing rate; $\Omega(f_t)$ is the natural curing effect. Due to the complexity of the natural curing process, the relationship between photovoltaic heating and curing should be analyzed.

$$\Omega(f_t) = K_T \cdot \alpha_i \cdot \sum_{j=1}^{T} \omega_j^i \tag{11}$$

where: α_i is the expansion and contraction coefficient; ω_j Curing results for different location points.

At the same time, if you need to compare the old and new concrete, the comparison function is $O_{bj}(\varphi)$.

$$O_{bj}(\varphi) = \sum_{i=1}^{n} \left[l\left(y_i, \hat{y}_i^{t-1}\right) \right] / \sum_{i=1}^{t} \Omega(f_t) \tag{12}$$

where: t is the number of comparisons, is the $l\left(y_i, \hat{y}_i^{t-1}\right)$ photovoltaic energy consumption function; $\hat{y}_i^{t-1}$ is the curing value of the repair location; and $f_t(x_i)$ is the difference in pore size between the old and new concrete. Finally, the difference of the repaired concrete should be calculated [11], if there is no difference between the old and new concrete, it means that the defect is repaired better, otherwise it needs to be repaired. Therefore, the calculation of differential repair is to derive and analyze the data before and after repair, and the derivation point is mainly to ω_j derive and order $O_{bj}(\varphi) \approx 1$. At the same time, the weight of the modification should be increased w^*, which is calculated as follows.

$$w^* = -\frac{G_j}{H_j + \lambda} \tag{13}$$

Among them, G_j is the modification standard of concrete, and H_j is repair value after derivation.

C. Evaluation Indicators of Concrete Repair

It mainly includes strength, pores, and gaps of complexes, which are calculated as follows.

If the concrete strength is expressed in terms R^2, it is calculated as follows.

$$R^2 = 1 - \frac{\sum_{i=1}^{n} \left(\hat{x}_i - x_i\right)^2}{\sum_{i=1}^{n} \left(x_i - \overline{x}\right)^2} \tag{14}$$

Among them, the $\sum_{i=1}^{n} (\hat{x}_i - x_i)^2$ concrete is after repaired, the $\sum_{i=1}^{n} (x_i - \overline{x})^2$ concrete is before repaired. Contrast the porosity of concrete $RMSE$, specifically as indicated.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left(\hat{x}_i - x_i\right)^i} \tag{15}$$

Porosity is mainly to analyze the repair pore size of concrete and test its water permeability, so the pore size of concrete is an important content of modification. The following is a judgment on the complex gap of concrete MAE, as follows.

$$MAE = \frac{1}{n} \sum_{i=1}^{n} \left|\hat{y}_i\right| - y_i \tag{16}$$

To sum up, the repair of concrete surface defects mainly involves the hardness of the material and the integration of the material. The use of photovoltaic heating technology is mainly to judge the energy consumption core of its repair, as well as the curing of concrete. After the above analysis, the overall index of concrete should be analyzed, mainly its porosity, permeability, complex gap, and overall strength after fusion.

3. Practical Case Analysis of Concrete Surface Defect Repair

A. Introduction to Concrete Surface Defects

According to the construction of the domestic WYTJ-07 bid section as the research object, the mixed material of concrete is: cement, fly ash, sand, stone and water, and the construction ratio is 1:0.5:0.3:0.2:0.7.

Table 1. Condition of Surface Defects

Name	Porosity/mm	Crack Location
Patch Case 1	/	/
Patch Case 2	500	Crack 1
Working Conditions Three	600	Crack 1
Working Conditions Four	700	Crack 1
Patch Case 3	700	Crack 1 + Crack 2
Patch Case 4	700	Crack 3 + Crack 4

Table 1 shows the information of randomly selected defects, which need to be repaired and maintained. Among them, photovoltaic heating adopts polysilicon heating panels, the heating material is mainly resistance wires, and is covered on the concrete surface through the form of mesh laying, and the concrete is watered and cured by special personnel every 12 hours. The curing standards after the repair of concrete surface defects meet the construction requirements, and its operation is consistent with that of natural repair. The data collected by concrete is shown below.

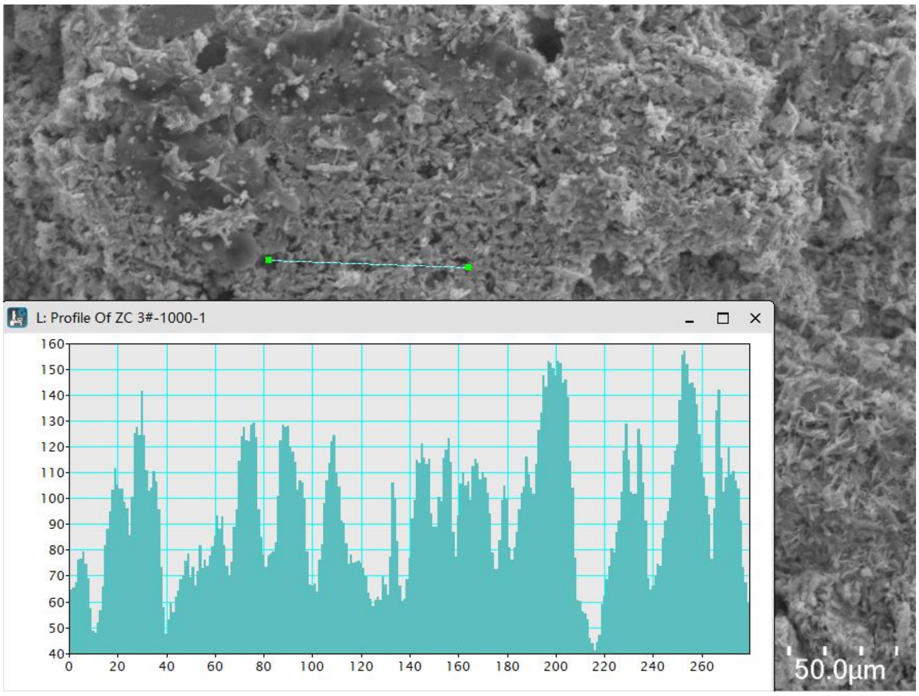
Table 2. Maintenance of Concrete Surface Defects

Time	Watering Frequency (times)	Temperature Regulation (times)	Sampling	Remark	Weather
1d	0.000	0.000	0	It's no different.	Sunny, 22~25°C
2d	0.000	0.000	0	It's no different.	
3d	0.000	0.000	0	It's no different.	
4d	0.995	0.995	1	Dry	
5d	2.980	2.980	1	Dry	
6d	3.898	3.898	1	Dry	Cloudy to Clear, 21~23°C
7d	0.000	0.000	0	Dry	
8d	0.000	0.000	0	It's no different.	
9d	3.736	3.736	0	It's no different.	
10d	3.050	3.050	1	Dry	
11d	0.000	0.000	0	Dry	
12d	4.210	4.210	1	It's no different.	
13d	0.000	0.000	0	It's no different.	Showers, 16~18°C
14d	0.969	0.969	1	It's no different.	
15d	1.688	1.688	1	It's no different.	
16d	3.734	3.734	1	It's no different.	
17d	0.000	0.000	0	It's no different.	Sunny, 24~26°C
18d	0.000	0.000	0	It's no different.	
19d	0.000	0.000	0	It's no different.	
20d	0.000	0.000	0	It's no different.	
21d	0.000	0.000	0	It's no different.	
1d	0.000	0.000	0	It's no different.	

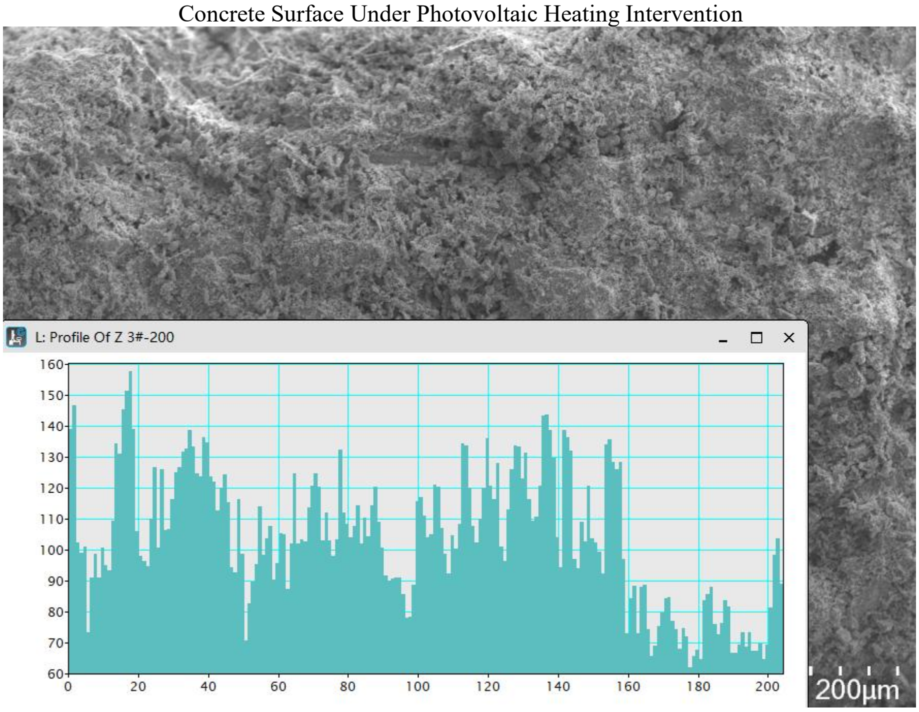
From the results in Table 1, it can be seen that the concrete curing standards in the process of repairing the autumn leaf line on the concrete surface are in line with the normal requirements, and there are no other abnormalities, which only shows that the interference rate of human factors in the curing process of the whole concrete is almost zero, which can be used as a later maintenance study.

B. Analysis of Porosity and Complex Spacing After Concrete Surface Repair

If the pore spacing and complexes of the concrete surface after repair are analyzed, the relationship between the pore size and the structure and matter is mainly observed, and the specific results are shown in the figure below.



Concrete Surface Under Photovoltaic Heating Intervention



Naturally Dry Concrete Surface

Figure1. Comparison of Porosity and Complex Spacing on Concrete Surface Under Photovoltaic Heating

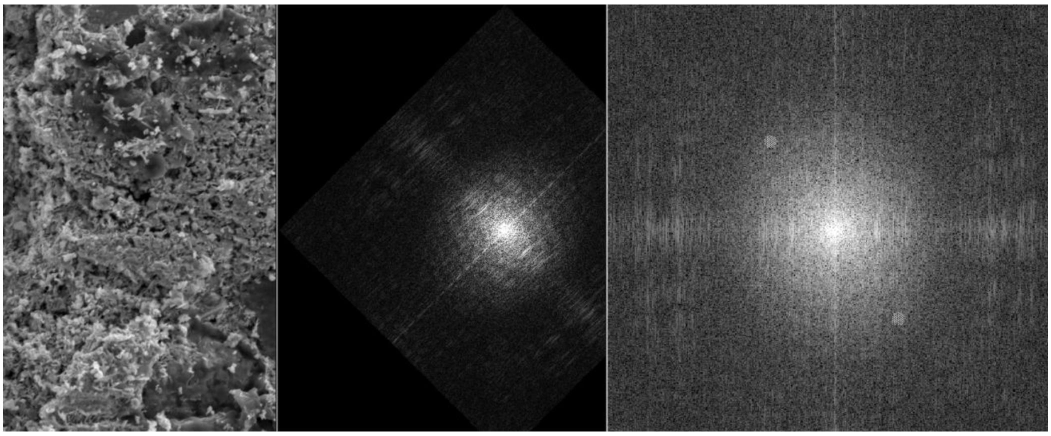
From the analysis results of Figure 1, it can be seen that the pore diameter of concrete under photovoltaic heating is less than 50 microns, and the pore diameter of concrete after natural drying is 200 microns, a difference of 4 times. The surface flatness of the concrete after photovoltaic heating intervention was relatively flat, while the naturally dried surface had a large rough surface. Photovoltaic heating has been shown to be effective in promoting the curing of concrete and reducing the permeability of concrete. By observing the pore size of the concrete surface after photovoltaic heating, it is found that the spacing of the problem complex is relatively small, and the pore size after natural drying is larger, mainly due to the large temperature difference or the change of dryness, resulting in a large gap between the concrete complexes. Photovoltaic heating has great advantages in curing and clearance, which can improve the flatness of the concrete surface, reduce the permeability of concrete after repair, and then extend the service life.

Table 2. Comparison of Concrete Surface Defect Repair

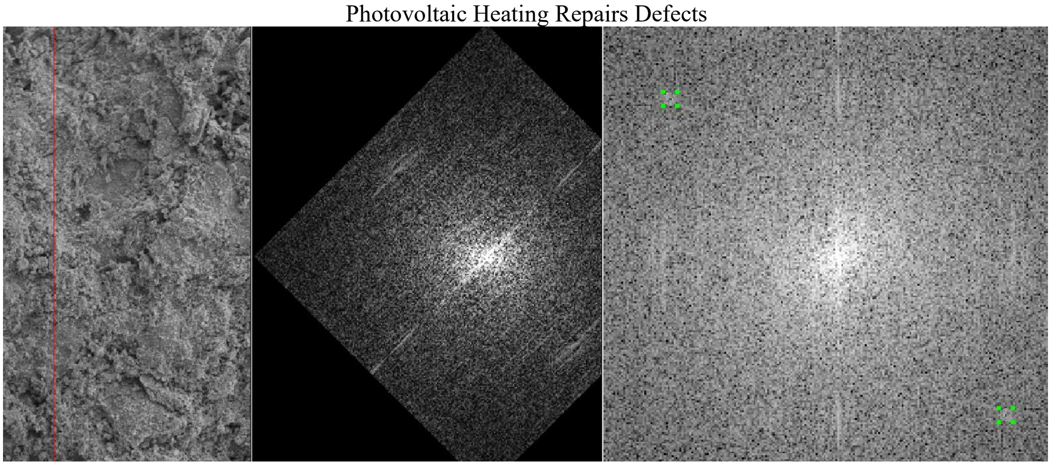
Grouping	Index	Minimum	Maximum	Average	Standard Deviation	Median

Grouping	Index	Minimum	Maximum	Average	Standard Deviation	Median
Photovoltaic Heating	Strength (Kpa)	0.689	6.456	1.489	1.423	0.921
	Porosity (microns)	0.984	5.020	1.001	0.009	0.998
	Complex Spacing (microns)	50.697	54.891	52.790	1.349	50.680
Natural Drying	Strength (Kpa)	0.197	4.891	2.790	1.349	2.680
	Porosity (microns)	0.512	4.617	2.695	1.588	3.350
	Complex Spacing (microns)	192.669	204.210	200.807	1.269	3.050

The data in Table 2 shows that photovoltaic heating can promote the repair of surface defects of concrete, improve the repair effect, and enhance its strength. Moreover, comparing the spectral analysis tables for concrete surface defect repair, we can see that there is a huge difference between the two, as shown in the figure below.



Photovoltaic Heating Repairs Defects



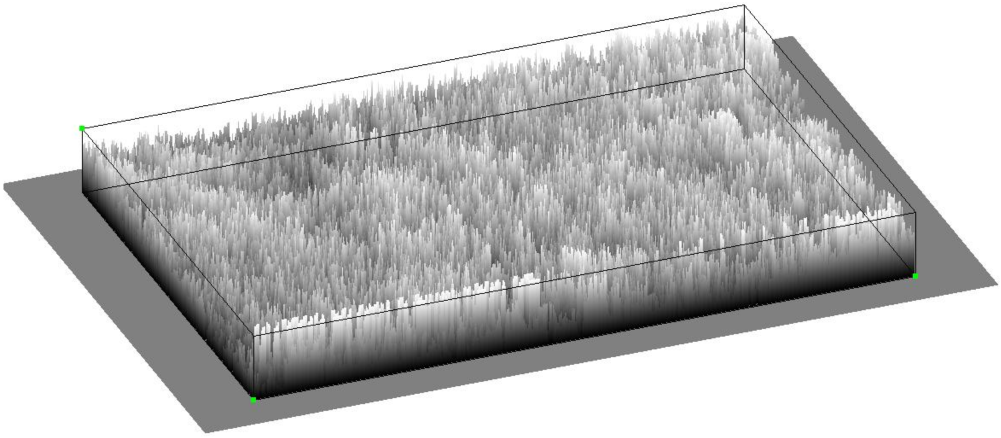
Natural Drying Repairs Defects

Figure 2. Comparison of Defects Repaired by Different Methods

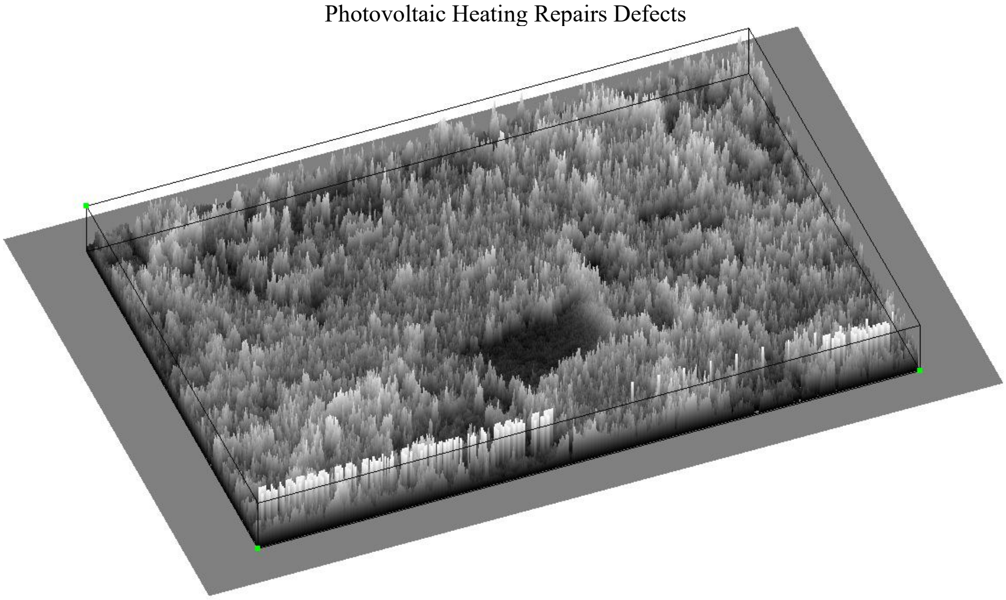
From the data analysis in Figure 2, it can be seen that the gap between the defective particles after photovoltaic heating repair is relatively small, and the overall density is large. Comparatively speaking, the particle gap after natural drying repair is relatively large, and the density is small, and its compressive ability is relatively weak.

C. Energy Consumption and Cost After Concrete Surface Repair

The energy consumption of concrete surface repair under different intervention methods was compared, and the spectral diagram was reflected, as follows.



Photovoltaic Heating Repairs Defects



Natural Drying Repairs Defects

Figure 3. Comparison of Energy Consumption of Different Defect Repair Methods

From the comparison of the repair defect repair methods in Figure 3, it can be found that the photovoltaic heating analysis method has the advantage of low energy consumption for the repair of concrete surface defects, and the overall energy consumption reduction rate is 60% of that of natural drying. Among them, the energy consumption after photovoltaic heating shows fluctuating changes, mainly because of the change of light intensity, resulting in the difference in photovoltaic energy conversion, but on the whole, the heating stability of the photovoltaic heating method is relatively high, and there is no large fluctuation, while the natural drying method is affected by the weather. It shows that the natural drying method can continuously repair the concrete surface to ensure the stability of temperature and humidity, and has a significant effect on the curing of concrete and the increase of its own strength.

Table 3. Cost of Repair of Surface Defects of Different Concrete [Unit: 1000 yuan/m2]

Range	Type	The Mean ± Standard Deviation	Sue for Peace	Median	Mean 95% CI (UL)	Kurtosis	Skewness	Cost Adjustment Factor (CV)
Photovoltaic Heating Method	Fissure	Select Size 1,489±1,423	35.745	0.921	2.059	1.490	1.123	15.528%
	Concavity	Select Size 1.001±0.009	24.019	0.998	1.005	-0.387	0.378	10.929%
	Collapse	52.790±1.349	76.959	2.680	3.330	-1.187	0.070	10.700%
Natural Drying Method	Fissure	2.790±1.349	66.959	2.680	3.330	-1.187	0.070	28.348%
	Concavity	Reference: 2.695±1.588	2.521	2.680	2.250	3.122	-3.782	28.906%
	Collapse	72.807±1.269	751.610	3.350	4.658	2.476	-3.419	35.211%

From the data analysis in Table 3, it can be seen that the construction cost of collapse is the largest, followed by the construction cost of cracks. Compared with the two methods, the construction cost of cracks, depressions and collapses of the photovoltaic heating method is lower than that of the natural drying method. Among them, in terms of median, kurtosis and skewness, the photovoltaic heating method was lower than that of the natural drying method, and some values were negative, mainly because the weather and other factors affected the cloudy days of 10~15d in the case study in this paper, so the repair cost increased. In terms of cost adjustment coefficient, the adjustment rate of the photovoltaic heating method is lower than that of the natural drying method, mainly because photovoltaic heating can convert light energy into heat energy and heat the concrete surface to maintain dryness. However, the natural drying method needs to be adjusted manually, and there is a certain deviation.

4. Conclusion

Photovoltaic new energy technology is increasingly widely used in various fields, and the application in the concrete heating process is relatively rare, mainly due to the lack of necessary cases, especially the surface defect repair work cases in the later stage of concrete. Based on new energy technology, this paper makes an in-depth analysis of the defect repair of concrete surface and discusses the relationship between the two. The results show that the photovoltaic heating method can maintain a constant increase in the surface temperature of concrete, and its strength can reduce the air and depression rate, and the increased range is between 10%~20%. At the same time, photovoltaic heating can narrow the gap between complexes, enhance the flatness and compressive ability of the concrete surface, and reduce the phase by about 10%. For artificial concrete maintenance, the photovoltaic heating method can maintain the constant temperature and humidity of the concrete surface, reduce the cost of depression repair, and the reduction rate reaches 20~30%. The above analysis shows that the application of new energy technology in the field of concrete is practical, and it can achieve low cost and low energy consumption of surface repair, improve the strength of concrete surface, and promote the later maintenance of concrete. There are also some deficiencies in the research process, which mainly reflects the selection of research objects, only for C10 concrete, and no horizontal comparison of other multi-grade concrete, which will be studied in depth in the future to make up for the lack of research in this paper.

References

[1] Y. L. Deng, J. J. Wang, D. Xia, and L. L. Xu, "The impact of political competition on low-carbon technology innovation: From the perspective of officials' personal characteristics," *Energy & Environment*, Oct. 2023, doi: 10.1177/0958305x231205516.

[2] S. Dermühl and U. Riedel, "A comparison of the most promising low-carbon hydrogen production technologies," *Fuel*, vol. 340, May 2023, doi: 10.1016/j.fuel.2023.127478.

[3] Y. L. Hou, S. J. Tai, X. M. Li, M. Zhang, G. K. Fu, and C. Q. Zhang, "Evaluation on key technologies for the construction of low-carbon index of electric power based on "double carbon"," *International Journal of Emerging Electric Power Systems*, vol. 24, no. 4, pp. 499-509, Aug. 2023, doi: 10.1515/ijeeps-2023-0061.

[4] J. H. Kang and G. L. Zhao, "A low carbon treatment technology of green building construction waste based on genetic algorithm," *International Journal of Global Energy Issues*, vol. 45, no. 4-5, pp. 408-420, 2023, doi: 10.1504/ijgei.2023.132012.

[5] R. R. Liang, N. Tao, J. Y. Li, and F. Meng, "Traffic sign recognition with low-carbon technology in nighttime environment based on deep learning," *International Journal of Low-Carbon Technologies*, vol. 18, pp. 727-736, Feb. 2023, doi: 10.1093/ijlct/ctad049.

[6] N. Saqib, M. Radulescu, M. Usman, D. Balsalobre-Lorente, and T. Cilan, "Environmental technology, economic complexity, renewable electricity, environmental taxes and CO2 emissions: Implications for low-carbon future in G-10 bloc," *Heliyon*, vol. 9, no. 6, Jun. 2023, doi: 10.1016/j.heliyon.2023.e16457.

[7] I. Sengor, L. Mehigan, M. A. Zehir, J. J. Cuenca, C. Geaney, and B. P. Hayes, "Voltage constraint-oriented management of low carbon technologies in a large-scale distribution network," *Journal of Cleaner Production*, vol. 408, Jul. 2023, doi: 10.1016/J.JCLEPRO.2023.137160.

[8] W. L. Shang and Z. H. Lv, "Low carbon technology for carbon neutrality in sustainable cities: A survey," *Sustainable Cities and Society*, vol. 92, May 2023, doi: 10.1016/j.scs.2023.104489.

[9] S. Y. Tan and G. M. Liu, "A low carbon management model for regional energy economies based on blockchain technology," *Heliyon*, vol. 9, no. 9, Sep. 2023, doi: 10.1016/j.heliyon.2023.e19966.

[10] T. C. Wang and B. M. Suo, "Low-carbon electricity technology transformation in Chinese universities," *International Journal of Climate Change Strategies and Management*, Mar. 2023, doi: 10.1108/ijccsm-08-2022-0121.

[11] C. Y. Zhao, K. Y. Dong, K. Wang, and X. C. Dong, "Can low-carbon energy technology lead to energy resource carrying capacity improvement? The case of China," *Energy Economics*, vol. 127, Nov. 2023, doi: 10.1016/j.eneco.2023.107092.