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Test of Mechanical Properties of Composite Recycled Concrete After Medium and High Temperature

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Abstract

Compressive strength is one of the important indexes to test the mechanical properties of concrete. The compressive strength of recycled composite concrete after high temperature is studied by single factor experimental analysis and double factor experimental analysis. Combined with variance analysis, the influence of replacement rate of recycled aggregate, volume incorporation amount of polypropylene fiber and volume incorporation amount of nani CaCO3 on compressive strength of recycled concrete after high temperature was systematically studied. The results show that when the replacement rate of recycled aggregate is 50%, the volume incorporation amount of polypropylene fiber is 0.08%, and nani CaCO3 is 1.2%, the compressive strength of composite recycled concrete reaches the maximum value. Nano CaCO3 is the most significant factor affecting the compressive strength of recycled concrete after high temperature. The significant influencing factors are the incorporation amount of polypropylene fiber and the replacement rate of recycled aggregate.

Keywords

Composite material, medium and high temperature, recycled concrete, single factor analysis, double factor analysis.

1. Introduction

According to statistics, up to 2020, the total output of construction waste in our country has exceeded 20 billiont, construction waste has increased by nearly 4 billiont per year, and has formed the highest total output of solid waste in the world[1] . At present, the disposal methods of construction waste in China are only to be taken to barren mountains for simple landfill and dump. These disposal methods not only waste a lot of resources, but also do harm to the preservation of natural environment. Therefore, to find a green, environmental protection, efficient water treatment method is particularly important.

Some scholars at home and abroad have made a preliminary discussion on the research of recycled concrete after high temperature, but the conclusions are different, and the research on recycled concrete after high temperature is relatively few, the reinforcing effect of nano-CaCO3 on the mechanical properties of recycled aggregate concrete was studied by Qu Chengping[2] and other scholars. The results show that nano-CaCO3 solution has obvious reinforcing effect on recycled aggregate, and the early effect is better than the later one.

Zhou Peng, Liu Yongjun[3] based on the analysis of mechanical properties of polypropylene fiber recycled concrete by orthogonal experiment, the results show that the content and length of polypropylene fiber are important factors affecting the strength of recycled concrete.

Hou Lina[4] on the fiber reinforced recycled concrete mechanical properties and prospects of the article, the use of fiber reinforced recycled concrete reinforced modification of the formation of fiber reinforced recycled concrete, for the natural defects of recycled concrete can play a certain role to make up for, to protect the natural environment is of great significance. The reinforcement effect and influence law of different kinds of fibers on basic mechanical

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properties and dynamic properties of recycled concrete at room temperature and high temperature are emphatically expounded, it provides the experience for the next research on fiber recycled concrete.

Liu Xiaoyan; Liu Li[5]In order to optimize the effect of RCP on cement-based materials, the hydration and mechanical properties of RCP-doped cement-based materials were studied by using nanoscale silicon dioxide (NS) . The results show that the setting time of RCP-cement paste is significantly shortened, while the early hydration rate and heat of hydration are increased after adding NS into RCP-cement paste. In addition, the mechanical strength of mortar decreases when RCP replaces part of cement, and 2% NS can compensate the loss of mechanical strength caused by RCP as supplementary cementitious material.In order to optimize the effect of RCP on cement-based materials, the hydration and mechanical properties of RCP-doped cement-based materials were studied by using nanoscale silicon dioxide (NS) . The results show that the setting time of RCP-cement paste is significantly shortened, while the early hydration rate and heat of hydration are increased after adding NS into RCP-cement paste. In addition, the mechanical strength of mortar decreases when RCP replaces part of cement, and 2% NS can compensate the loss of mechanical strength caused by RCP as supplementary cementitious material.

Cui Zhenglong, Sun Wanji and other scholars[6] have studied the damage evolution law of recycled concrete at high temperature of carbonization. The results show that the damage location, cumulative impact count and energy count of recycled concrete are analyzed, it can realize the dynamic monitoring of the whole process of the axial compression failure of recycled concrete from the initial damage to the evolution of micro-cracks, then to the propagation of macro-cracks, and finally to the failure of the specimen, the concentrated position of the damage points during loading is consistent with the final damage position of the specimen.

The influence of the doping rate of nano-CaCO3, water-binder ratio, sand ratio and the doping rate of recycled coarse aggregate on the compressive strength of recycled cement was studied by orthogonal test. The results show that nano-CaCO3 can also improve the compressive strength of recycled cement, especially the early compressive strength[9].

Li Jianpei's research[8] work on the dynamic characteristics of recycled concrete heated in air. Research results: with the gradual rise in temperature, the recycled concrete said the visual color gradually changed from cyan-gray to brown-yellow, then to gray-white, and finally to white-yellow. Therefore, it is necessary to carry out the compressive test of recycled concrete with the replacement ratio of recycled aggregate, the volume addition of polypropylene fiber and the volume addition of nano-CaCO3 as the experimental factors. In this paper, the effects of recycled aggregate substitution rate, volume addition of polypropylene fiber and volume addition of nano-CaCO3 on the compressive strength of recycled concrete after high temperature are studied systematically, in order to provide the basis for the application in the project.

2. Indoor Test

2.1. Experimental materials

The coarse aggregate selected in this experiment is divided into natural coarse aggregate and recycled coarse aggregate. The natural coarse aggregate selected in the experiment is taken from Anyang. The apparent density of the natural coarse aggregate is 2700km3, and the recycled coarse aggregate is C35 concrete solid block with original strength, after the crushing process, clean and dry, as shown in Figure 1.

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Figure 1. Recycled coarse aggregate after cleaning

Cement as an important component of concrete, in the selection of cement should pay attention to its various indicators, and also economical, but also have good compatibility with water reducer. The cement selected in this experiment is Anyang Lake PO42.5 R grade cement with apparent density of 3100 kg/m^3. The chemical composition is shown in Table 1.

Fine aggregate is used to fill the gap between coarse aggregate. The fine aggregate selected in this experiment is natural river sand with fineness modulus of 2.7, apparent density of 2650 kg/m^3 and mud content of 1.04% . The basic properties of fine aggregate are shown in table 2.

Nani-CaCo3, as a kind of nano-powder material, can not only fill micro-aggregate into concrete, but also enhance the interface of cement-stone. The particle size of nano-calcium carbonate is 15nm ~ 40nm. The physical properties of nanometer calcium carbonate are shown in table 3.

Table 1. Chemical composition of cement

SiO2	AL2O3	Fe2O3	CaO	Mg0	SO3	Loss of quantity by burning	Other
20.08	5.37	3.96	63.28	1.71	2.63	2.27	0.70

Table 2. Chemical composition of fine aggregate

Type	Soil content/%	Bulk density/(kg.m^{-3})	Apparent density/(kg.m^{-3})	Modulus of fineness	Moisture Content/%
Fine aggregate	2.3	1650	2665	3.6	1.0

Table 3. Chemical constituents of nano-CaCO3

Average particle size(nm)	specific surface area(m^2/g)	Purity%	PH	Loss of quantity by burning%
15~40	40	98.9	8.5~10.5	Qualified

2.2. The experimental process

Firstly, the recycled concrete with strength grade C35 is prepared according to the mix proportion of ordinary concrete, and the additional water isincreased according to the effective water absorption of recycled aggregate[9] , the mixed concrete was poured into the test mould and put on the shaking table to vibrate, then put into the standard curing room with thetemperature of (20 ± 2) OC and the relative humidity more than 95% For the specimens of a certain age, the specimens are heated at 300°C in the incubator and heated at constant temperature for one hour after the incubator reaches 300°C to ensure that the heating

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temperature inside thespecimen reaches the room temperature after cooling, the loading test is carried out by the WEW-1000A Universal Testing Machine.

3. Single-factor and Two-factor Analysis of Experimental Scheme and Experimental Results

In this experiment, three factors were considered: (1) substitution rate (0% , 25% , 50% , 75%) ; (2) nano-CaCO3 incorporation (0.4% , 0.8% , 1.2% , 1.5%) ; (3) the volume fraction of polypropylene fiber (0.04% , 0.08% , 0.10% , 0.12%) . The final experimental results are shown in table 4.

4. Single Factor Analysis of Experimental Results

Let a single factor A have R levels A1, A2... Ar, Ni (i = 1,2... n) was done at each level, and one-way steps were as follows[9] .

4.1. Analysis process

The procedure of one-way Anova is as follows:
calculate the average

Table 4. Compressive strength of composite recycled concrete

Experiment number	Compressive strength/MPa		
Z00	35	36.3	34.0
Z25	36.2	36.3	35.9
Z50	38.3	38.0	38.6
Z75	37.8	38.2	37.5
N04	33.8	34.1	33.5
N08	38.3	38.9	37.6
N12	38.7	38.8	38.2
N15	39.5	39.1	39.9
J04	36.0	35.5	36.4
J08	38.3	38.1	38.6
J12	37.6	37.1	38.1
J15	36.1	37.0	35.5

Z-recycled aggregate substitution rate, N-nano-CaCO3 incorporation rate, J-polypropylene fiber incorporation rate; numbers indicate percentages, as Z25 indicates recycled aggregate substitution rate of 25% .

Let $\bar{x}_i$ be the arithmetic mean of all the experimental values at Level I(1)

$$\bar{x}_i = \frac{1}{n_i}\sum_{j=1}^{n} x_{ij} \, (i = 1,2.....n) \tag{1}$$

Then the sum within the group is invisible(2)

$$T_i = \sum_{j=1}^{n} x_{ij} = n_i \bar{x}_i \tag{2}$$

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$\bar{x}_i$ For the arithmetic mean of all the experiments，n Represents the total number of experiments.

calculate the sum of squares of deviations

Sum of squares of total deviations(3)

$$S_T = \sum_{i=1}^{r}\sum_{j=1}^{n}(x_{ij} - \bar{x})^2 \tag{3}$$

S_T Represents the sum of squares of the deviations between the test values and the total mean, reflecting the total difference between the test results.

The sum of squares of deviations between groups(4)

$$S_A = \sum_{i=1}^{r}\sum_{j=1}^{n}(\bar{x}_i - \bar{x})^2 = \sum_{i=1}^{r} n_i(\bar{x}_i - \bar{x})^2 \tag{4}$$

S_A Represents the sum of squares of the differences between groups for factor A, reflecting the extent to which the differences between the within-group averages are due to the different effects of different levels of factorA, the sum of squares of deviations between groups is also called the sum of squares of deviations of horizontal terms.

Sum of squares of intra-group deviations(5)

$$S_e = \sum_{i=1}^{r}\sum_{j=1}^{n}(x_{ij} - \bar{x}_i)^2 \tag{5}$$

S_e Represents the sum of squares of within-group deviations, reflecting theextent to which factors vary within levels and between test values, and that this difference is due to the effect of random errors, the sum of squares of deviations is also called the sum of squares of deviations of horizontal terms.

Calculate degrees of freedom

Calculate the degrees of freedom(6)(7)(8).

$$df_T = n - 1 \tag{6}$$

$$df_A = r - 1 \tag{7}$$

$$df_e = n - r \tag{8}$$

df_T—Total degree of freedom; df_A—Degree of freedom between groups; df_e—Degree of freedom within a group.

F Inspection

Comparing the sum of squares of the mean deviations of each factor withthe sum of squares of the mean deviations of the errors respectively, the F values are shown in the formula (9).

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$$F_A = \frac{S_A / df_A}{S_e / df_e} = \frac{MS_A}{MS_e} \tag{9}$$

4.2. Results of analysis of variance

The calculation is based on the data in table 4 above, considering the practicability in engineering, for $\alpha = 0.05$, F0.05(3, 8)=4.066. The results are in table 5 ~ 7.

Table 5. Analysis of variance of compressive strength of recycled aggregate

Analysis of variance						
Source of difference	SS	df	MS	F	P-value	F crit
Between groups	13.72	3	4.573	9.333333	0.005441	4.066181
Of the project	3.92	8	0.49			
Total	17.64	11				

Table 6. variance analysis of polypropylene fiber content to composite recycled concrete after high temperature

Analysis of variance						
Source of difference	SS	df	MS	F	P-value	F crit
Between groups	10.66917	3	3.556389	11.85463	0.002585	4.066181
Of the project	2.4	8	0.3			
Total	13.06917	11				

Table7. Effect of nano-CaCO3 content on compressive strength of composite recycled concrete after high temperature

Analysis of variance						
Source of difference	SS	df	MS	F	P-value	F crit
Between groups	56.176	3	18.72556	132.180	3.73E-07	4.06618
Of the project	1.1333	8	0.141667			
Total	57.31	11				

From the analysis of variance in table 5 ~ 7, we can clearly find that the most significant influence on the compressive strength of the composite recycled concrete after high temperature is the amount of nano-CaCo3, followed by the amount of polypropylene fiber, finally, the replacement rate of recycled aggregate.

4.3. Analysis of compressive strength of each factor

(1) The effect of replacement ratio of recycled aggregate on compressive strength

According to the previous research, recycled aggregate replacement has the greatest impact on the compressive strength of recycled concrete, so this experiment aims at the replacement rate of recycled aggregate for the cubic compressive strength of recycled concrete, the content of nano-CaCO3 was 1.2% , and the content of polypropylene fiber was 0.08% . The equation of the effect of recycled aggregate substitution rate on compressive strength is fitted as shown in Figure 2 below.

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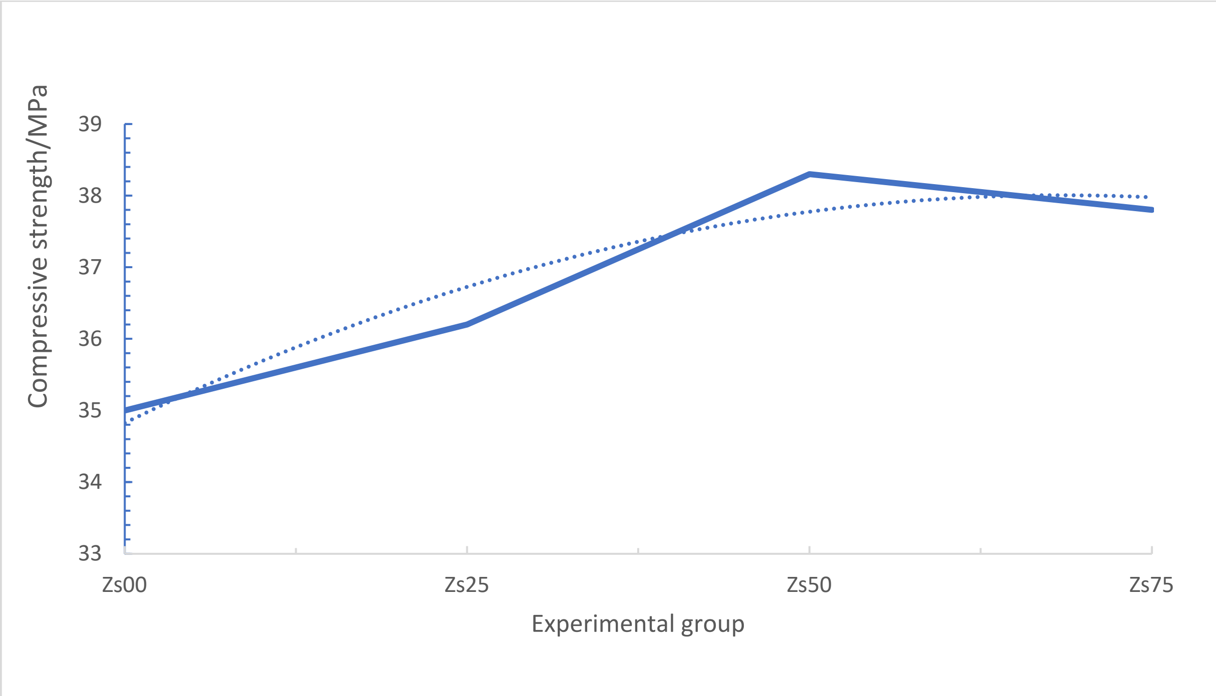

Figure 2. Relationship between recycled aggregate and compressive strength and fitting curve

As can be seen from the figure above, the compressive strength of recycled concrete reaches its maximum value when the replacement ratio of recycled aggregate is 50% , and the compressive strength of recycled concrete should decrease with the increase of recycled aggregate without high temperature heating, but this experiment after high temperature heating treatment as shown in figure 3.2 above. The main reason for this is that the free water in the recycled concrete is evaporated after high temperature treatment, the clinker is further hydrated, the compressive strength is increased, and the higher the replacement rate of recycled aggregate is, the more free water in the recycled concrete, the better the hydration reaction, but with the increase of the replacement rate of recycled aggregate, the defects of recycled aggregate are further magnified, the compressive strength of recycled concrete will decrease. The fitting equation of the relationship between the replacement rate and compressive strength of recycled concrete after high temperature is shown in formula (10) , and the fitting equation R2 = 0.9106, which shows that the equation is well fitted and has credibility.

$$y = 0.425x^2 + 3.175x + 32.075 \tag{10}$$

(2) Effect of nano-CaCO3 on compressive strength of recycled concrete

Nano-CaCo3 also has some influence on the compressive strength of recycled concrete. In this experiment, the effect of nano-CaCo3 on recycled concrete after high temperature is analyzed by controlling the amount of recycled aggregate and polypropylene fiber, the content of recycled aggregate and polypropylene fiber is 50% and 0.08% respectively.

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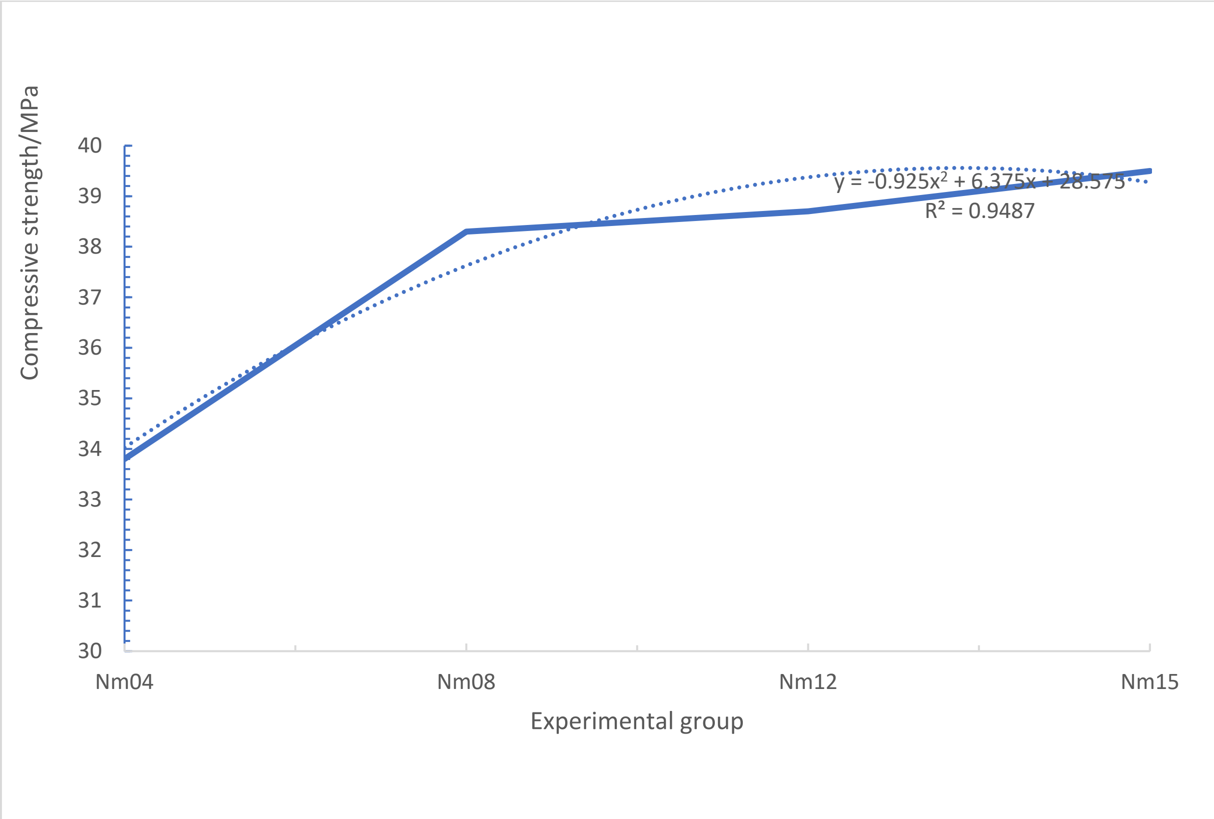

Figure 3. Relationship between nano-CaCO3 and compressive strength and fitting curve

According to Figure 3, it can be found that the compressive strength of recycled concrete increases with the addition of nano-CaCO3 and the addition of nano-CaCO3 increases from 0.4% to 0.8% , after the increase of nano-CaCO3,, the compressive strength of recycled concrete is also increased, but the effect is not significant, the main reason for this phenomenon is that nano-CaCO3 plays an important role in the filling of micro-aggregate and nucleation of recycled concrete. When the content of nano-CaCO3 reaches 0.8% , the filling effect is very good, after increasing the amount of nano-CaCO3 for the role of recycled concrete is not obvious before, so this phenomenon is caused. The fitting equation of the compressive strength of recycled concrete after high temperature and the content of nano-CaCO3 is shown in Formula (11) . The R2 of the fitting equation is 0.9487, which shows that the equation fits well.

$$y = 0.925x^2 + 0.375x + 28.575 \tag{11}$$

(3) Effect of polypropylene fiber on compressive strength of recycled concrete

According to previous researchers' research, polypropylene fiber has a certain impact on the compressive strength of recycled concrete, this experiment through controlling the amount of recycled aggregate and nano-CaCO3, the effect of polypropylene fiber on recycled concrete after high temperature is analyzed. The content of recycled aggregate and nano-CaCO3 is 50% and 0.8% respectively. See Figure 4 for details.

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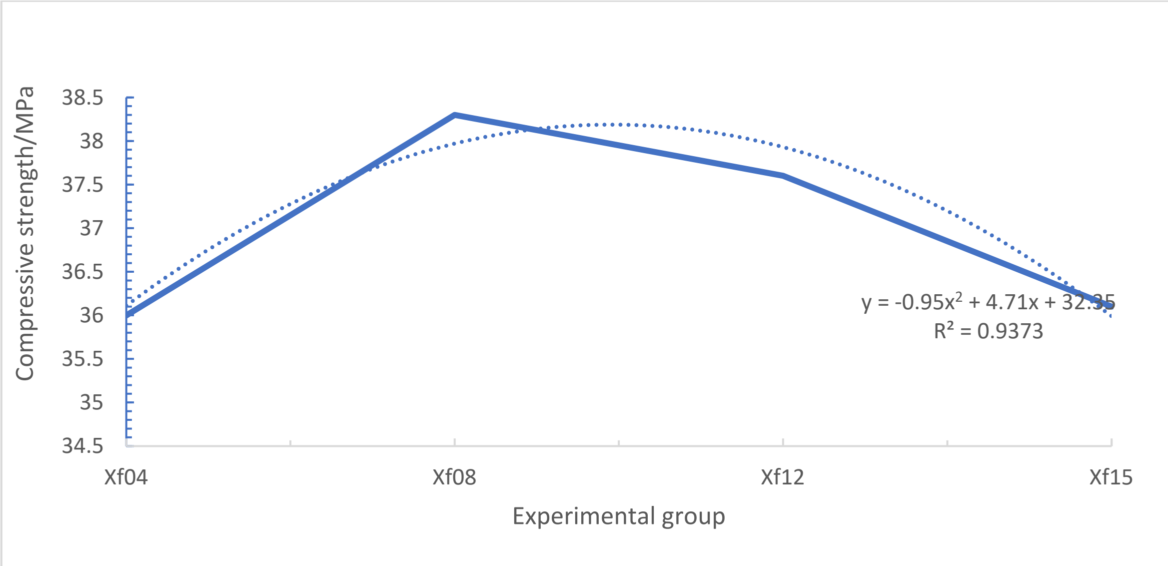

Figure 4. The relation between polypropylene fiber and compressive strength and the curve of fitting

According to Figure 4, it can be found that the compressive strength of recycled concrete increases first and then decreases with the increase of the amount of polypropylene fiber, and the amount of polypropylene fiber increases from 0.04% to 0.08% , the compressive strength of recycled concrete increases most significantly, and then the compressive strength of recycled concrete decreases gradually as the amount of polypropylene fiber increases, the main reason for this phenomenon is that adding a certain amount of polypropylene fiber into the concrete can effectively improve the compactness of the concrete, reduce the porosity in the concrete and improve the compressive strength of the concrete, but when the amount of polypropylene fiber is too much, the concrete is easy to appear the phenomenon of bunching, and because the fiber distribution is not uniform, resulting in different porosity increase, this phenomenon is caused by the fact that the compressive strength of the internal structure is reduced due to the porosity of the internal structure. The fitting equation (12) for the compressive strength of recycled concrete after high temperature and the content of polypropylene fiber is shown. The R2 of the fitting equation is 0.9373.

$$y = -0.95x^2 + 4.71x + 32.35 \tag{12}$$

5. Conclusion

(1) From the single-factor analysis of variance, we can clearly find that the most significant influence on the compressive strength of the composite recycled concrete after high temperature is the addition of nano-CaCO3, followed by the addition of polypropylene fiber, finally, the replacement rate of recycled aggregate.

(2) The interaction of composite materials has a significant effect on the compressive strength of concrete, so the addition of composite materials on the strength of recycled concrete is not only a simple superposition effect, but also the interaction between composite materials.

(3) When the replacement ratio of recycled aggregate is 50% , the volume addition of polypro pylene fiber is 0.08% , and the addition of nano-CaCO3 is 1.2% , the compressive strength of c omposite recycled concrete reaches the maximum.

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