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Research Article

Research on the Effect of Curing Temperature, Steel Fiber, and Admixture Content on Concrete Performance Based on Orthogonal Test in Cold Region

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Cold region covers over 50% all over the world. As an indispensable part of the project, concrete is greatly affected by temperature during the curing process. In this paper, through the orthogonal experiment design, we studied the mixing temperature, steel fiber, and water reducing agent dosage on concrete mixture slump; the influence of curing temperature, steel fiber, water reducing agent, and accelerating agent content on compressive strength of concrete; and the influence of the final microstructure by scanning electron microscopy (28-day concrete, analysis of the degree of hydration reaction). The results show that the slump of concrete increases with the amount of water reducing agent. Mixing temperature and steel fiber content have little effect on the workability of the mixture. Curing temperature has a significant effect on the growth of concrete compressive strength. The higher curing temperature is within 0~20°C, the faster the growth of concrete strength is. The longer the age of concrete, the greater the compressive strength. The content of water reducing agent and accelerating agent only has a significant effect on the early strength of concrete, while the content of steel fiber has a great effect on the late strength of concrete. Curing temperature affects the degree of hydration reaction of concrete. The higher the curing temperature, the more the cementing substances produced by hydration reaction of concrete, the higher the degree of hydration reaction, and the higher the strength of concrete. The research results are helpful to improve the mine support operation in high-cold and high-temperature difference area.

1. Introduction

Since its birth, concrete has been widely used in economic construction [1, 2]. Concrete itself is composed of a variety of substances [3], which are affected by many factors [4]. Concrete is formed by the solidification and hardening of cement in the mixture, and the aggregate is bonded into a dense and hard whole. The mechanical properties of concrete are affected by many factors, such as matrix strength, aggregate type [5], fiber type, and fiber content [6, 7]. In order to explore the influence of various factors on the performance of concrete, scholars at home and abroad have done a lot of research [8]. Hao et al. tested the influence of aggregate, admixture, mix ratio, and other factors on the strength of concrete. Wang et al. [9] studied the early curing system and found that the early strength of concrete increased significantly with the increase of the curing temperature and the extension of the curing time. Liu et al. [10] studied the effect of curing temperature on the strength development and frost resistance of low-temperature concrete [11]. Run-Xiao et al. [12] and Zhang et al. [13] studied the growth law of concrete strength under different curing temperatures and found that the curing temperature has an important influence on the strength of concrete. He and Kong [14] studied the mutual influence of curing temperature and prism size on the compressive properties of concrete specimens and found that low-temperature curing has an adverse effect on the development of concrete compressive strength and elastic modulus. Fan et al. [15] studied the strength and durability of shotcrete and the bonding strength between concrete and rock at different curing temperatures, and the results showed that the strength of concrete increased with the increase of temperature. Singh [16], Yao [17], Yuan et al. [17] studied the macroscopic strength characteristics of concrete from the macroscopic and microscopic structure of concrete and believed that the increase in curing temperature accelerated the rate of cement hydration reaction. Liang et al. [19] studied the effect of the interaction of water-binder ratio, air-entraining agent content, and curing temperature on the early strength and early impermeability of concrete through orthogonal experiments. The study found that the three factors have different effects on the strength of concrete. It is the water-binder ratio, curing temperature, and air-entraining dosage.

The abovementioned research has not carried out research on the influence of the interaction of curing temperature, steel fiber, water reducing agent, and quick-setting admixture on the performance of concrete. However, in engineering practice, the addition of materials [20, 21] plays a great role in improving the performance of concrete [22, 23]. For hydraulic concrete in alpine regions, the effect is particularly significant [24, 25]. This paper takes the natural caving method [26] and the bottom structure support of a mine [27, 28] in the alpine region of northwestern Yunnan as the engineering background and combines its four-season exposed and ground temperature changes to study the influence of the temperature of the mixture [29, 30], the water reducing agent, and the steel fiber content on the workability of the concrete mixture. Orthogonal experiments study the effect of the interaction of curing temperature, steel fiber, water reducing agent, and accelerator content on the compressive strength of concrete at different ages in order to provide a powerful reference for similar mine support.

2. Selection and Inspection of Test Materials

The sand and gravel materials are taken from the concrete mixing station of the mine and transported to the laboratory in a sealed manner. After mixing and shrinking, the test is carried out in accordance with the requirements of "Standard for Quality and Inspection Methods of Sand and Stone for Ordinary Concrete" JGJ52-2006. The moisture content of the sand in this test is measured to be 3.42%; in the nominal diameter of sand particles greater than 10 mm, 5~10 mm, 2.5~5 mm, 1.25~2.5 mm, 0.63–1.25 mm, 0.315–0.63 mm, and 0.16–0.315 mm and less than 0.16 mm, the cumulative sieve residue is 2.211%, 16.289%, and 39.673%, respectively. 59.33%, 72.00%, 83.89%, 92.22%, and 99.71%, with fineness modulus of 3.17, belong to the mixture of zone I sand and zone II sand (close to zone I sand). The stone powder content of the test sand is 14.37%, the mud content is 11.56%, and the crush value index is 62.5%. The mud content in the concrete aggregate has an impact on its strength. In order to fit the actual production of the mine, the test did not clean the sand and avoid changing its material composition.

P.0.425 ordinary Portland cement was used in the test with a specific surface area of 345 m^3/kg. Initial setting time is 208 min. Final setting time is 268 min. The 3-day flexural strength is 6.1 Mpa, and the 28-day flexural strength is 9.0 MPa. The 3-day compressive strength is 32.7 MPa, and the 28-day compressive strength is 53.0 MPa. The ignition loss is 4.35%; and the sulfur trioxide content is 2.45%, the magnesium oxide is 2.58%, chloride ion content is 0.015%, and grinding aid content is 0.06%. The stability of cement is qualified. The test water was the same as that of the mixing station. Part of the water was taken to the Material Composition Office of Kunming Metallurgical Research Institute for water quality inspection. It was found that the chloride content was 1.46 mg/L and the sulfate content was 22.6 mg/L, both of which met the requirements of the standard. The test uses the retarding polycarboxylic acid water reducer produced by Beijing Construction Engineering and the JY-240-type alkali-free liquid quick-setting admixture. The steel fiber used in the test is the end-hook-type steel fiber used for the underground support of the mine.

3. Mixture Slump Test

In order to investigate the influence of mixing temperature, steel fiber, and water reducing agent content on the slump of the mixture, the research team set the water-cement ratio to 0.63 and the lime-sand ratio to 0.262 according to the actual ratio of the mixing plant site and measured the slump of concrete mixture under the mixing temperature, the interaction of steel fiber, and water reducing agent content. The test plan and results are shown in Table 1.

According to Table 1, the three levels of mixing temperature, steel fiber content, and water reducing agent content are normalized according to thefollowing equation:

$$V_{ij} = \frac{X_{ij}}{X_{\max}}, \tag{1}$$

where V_{ij} is the normalized value, X_{ij} is the value of the jth level of the ith factor, and $X_{\max}$ is the maximum value of all the levels of all factors. The ternary phase diagram is drawn according to the value of V_{ij} and slump, as shown in Figure 1.

It can be seen from Figure 1 that the temperature of the mixture and the amount of steel fiber have little effect on its slump; the effect of the amount of water reducing agent is more obvious. The larger the amount of water reducing agent in the mixture, the greater the slump. According to the test results in Table 1, the influence of various factors on the slump of the concrete mixture is visually analyzed, as shown in Table 2.

The temperature of mixing material was named factor 1, the dosage of steel fiber was named factor 2, and the dosage of water reducing agent was named factor 3. Each factor has 3 levels. Y_n represents the result of group N test; for example, Y_7 represents the result of group 7 test, that is, the test result under the condition of mixing temperature of 12°C, steel fiber dosage of 35 kg/m^3, and water-reducing agent dosage of 8 kg/m^3, 179 mm. In Table 2, K_{ji} represents the sum of test results at the ith level of factor j; that is $K_{j1} = y_1 + y_2 + y_3$. In

Table 1: The effect of concrete mixture temperature, steel fiber, and water reducing agent on slump.

Number	Mixture temperature (°C)	Steel fiber content (kg/m^3)	Water reducing agent content (kg/m^3)	Slump (mm)
1	0	35	0	23
2	0	40	4	40
3	0	45	8	248
4	6	35	4	33
5	6	40	8	231
6	6	45	0	9
7	12	35	8	179
8	12	40	0	11
9	12	45	4	48

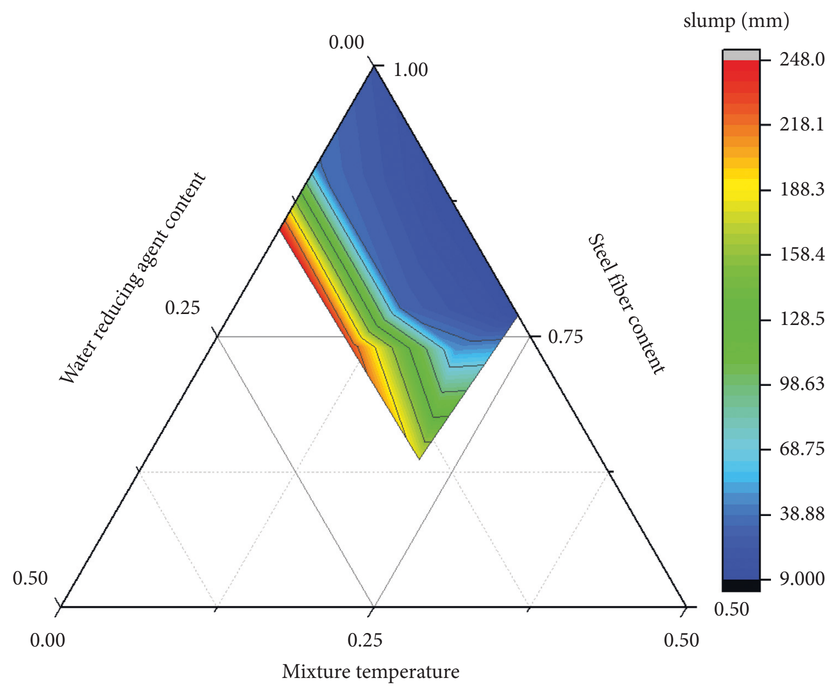

Figure 1: Three-phase diagram of the effect of mixing temperature, steel fiber, and water reducer dosage on slump.

Table 2: Visual analysis table of the effect of mixing temperature, steel fiber, and water-reducing agent on slump.

Observed value	Factor 1 (mixture temperature)	Factor 2 (steel fiber content)	Factor 3 (water reducing agent content)	Empty column	
K_{j1}	311	235	43	302	$K = 822$
K_{j2}	273	282	121	228	$P = 75076$
K_{j3}	238	305	658	292	$Q = 152630$
Q_j	75964.667	75924.667	149818	76150.667	
S^2_j	888.667	848.667	74742	1074.667	$S^2{}_T = 77554.000$
Range value	73	70	615	74	

addition, $K = y_1 + y_2 + \ldots + y_9$; $P = K^2/9$; $Q = y_1^2 + y_2^2 + \cdots + y_9^2$; $Q_j = (K_{j1}^2 + K_{j2}^2 + K_{j3}^2)/3$; $S_j^2 = Q_i - P$; $S_T^2 = S_1^2 + S_2^2 + S_3^2$. Range value $= \max_j (K_{j1}, K_{j2} K_{j3},) - \max_j (K_{j1}, K_{j2} K_{j3},)$.The meanings of these symbols and their operational relationships in Table 3 are similar to those in Table 2. This is not explained in the following article.

In the analysis of Table 2, it is not difficult to find that the amount of water reducing agent has a greater influence on the slump of the concrete mixture, and the influence of the temperature of the mixture and the amount of steel fiber on the slump is equivalent to that of the test error. The analysis of variance was performed with the above statistics, the significance level α was set to 0.05, and the corresponding F critical value was 19. The results are shown in Table 4.

According to the analysis of variance, it can be known that the mixing temperature and the amount of steel fiber have no significant influence on the slump of the concrete mixture, and the water reducing agent has a significant

Table 3: Visual analysis table.

Day	Observed value	Factor 1 (curing temperature)	Factor 2 (steel fiber content)	Factor 3 (water reducing agent content)	Factor 4 (accelerating agent content)	
1	K_{j1}	5.593	8.673	9.633	8.436	
	K_{j2}	8.929	8.723	9.546	8.143	$K=26.635$ $P=78.823$
	K_{j3}	12.113	9.239	7.456	10.056	$Q=87.697$
	Q_i	85.911	78.890	79.838	79.533	
	S^2_j	7.088	0.067	1.015	0.71	$S^2_T=8.88$
	Range value	6.52	0.566	2.177	1.913	
3	K_{j1}	16.813	19.713	18.683	19.703	
	K_{j2}	15.786	17.35	21.976	18.233	$K=56.672$ $P=356.857$
	K_{j3}	24.073	19.609	16.013	18.736	$Q=377.970$
	Q_i	370.461	358.046	362.805	357.229	
	S^2_j	13.604	1.189	5.948	0.372	$S^2_T=21.113$
	Range value	8.287	2.363	5.963	1.47	
7	K_{j1}	17.78	31.65	24.283	29.326	
	K_{j2}	24.033	22.423	32.200	28.596	$K=82.519$ $P=756.598$
	K_{j3}	40.706	28.446	26.036	24.597	$Q=880.710$
	Q_i	850.231	771.229	768.126	760.919	
	S^2_j	93.633	14.631	11.528	4.321	$S^2_T=124.116$
	Range value	22.926	9.227	2.639	1.576	
28	K_{j1}	38.537	50.460	38.923	45.070	
	K_{j2}	40.457	37.323	49.907	44.313	$K=134.02$ $P=1995.707$
	K_{j3}	55.026	46.237	45.190	44.637	$Q=2100.234$
	Q_i	2049.910	2025.693	2015.948	1995.803	
	S^2_j	54.203	29.986	20.241	0.096	$S^2_T=104.526$
	Range value	16.489	13.137	10.984	0.767	

Table 4: Variance analysis table of the effect of mixing temperature, steel fiber, and water reducer dosage on slump.

Type	S^2_j	Degree of freedom	Analysis of variance
Mixture temperature	888.667	2	0.827
Steel fiber content	848.667	2	0.790
Water reducing agent content	74742	2	69.549
Deviation	1074.667	2	
Sum	77554	8	

influence on the slump of the concrete mixture. Therefore, in actual production, you can focus on adjusting the amount of water reducing agent to increase the slump of the concrete and improve the conveying performance of the concrete mixture.

4. Mechanical Performance Test of Concrete Specimens

4.1. Test Protocol and Results. The mine is located in the southwestern high-cold area, and the underground temperature is low in winter and even freezes. The end-hook-type steel fiber, polycarboxylic acid water reducer, and JY-240-type alkali-free liquid accelerator are used in the support project. According to on-site construction conditions and technical parameters, four factors including curing temperature, steel fiber content, water reducing agent content, and accelerator content are considered, and three levels are considered for each factor, and orthogonal experiments are carried out. The orthogonal test design is shown in Table 5. In the test, the concrete specimens were made in strict accordance with the specifications, and the specifications of the specimens were 100 mm × 100 mm × 100 mm.

In order to fully restore the ambient temperature of the mixing site, the mixing water, cement, and gravel are frozen in the refrigerator before mixing the concrete, and the ice cubes are crushed during mixing, and the corresponding quality ice-water mixture is weighed according to the amount of water used for testing. The water reducing agent is added to the ice-water mixture before mixing according to the design, and the mixture is evenly stirred, and then the slump test is carried out. The quick-setting agent is mixed well with the mixture before being put into the mold. Place the specimens under the same curing temperature in the same curing box for curing to avoid uneven temperature distribution in the curing box caused by the test operation, thereby affecting the compressive strength of the same group of concrete specimens. The humidity of the curing condition

Table 5: Orthogonal test designs table.

Number	Curing temperature	Steel fiber content	Water reducing agent content	Accelerating agent content
1	0	35	0	63
2	0	40	4	68
3	0	45	8	73
4	6	35	4	73
5	6	40	8	63
6	6	45	0	68
7	12	35	8	68
8	12	40	0	73
9	12	45	4	63

Table 6: The compressive strength of concrete specimens at various ages.

Number	Compressive strength (MPa)			
	1 d	3 d	7 d	28 d
1	1.900	6.080	6.840	12.990
2	1.790	5.900	6.160	12.020
3	1.903	4.833	4.780	13.527
4	3.523	6.513	9.987	17.147
5	2.303	4.060	6.433	11.34
6	3.103	5.213	7.613	11.97
7	3.250	7.120	14.823	20.323
8	4.630	7.390	9.830	13.963

at 6°C is controlled within 25% to avoid icing to damage the specimen.

After the concrete sample has been cured to reach the predetermined age, the concrete compressive strength test is carried out according to the test specification. EM3.305-2 microcomputer-controlled electronic pressure testing machine is used to determine the compressive strength of concrete specimens with younger ages and lower strengths, and HYE-3000B electrohydraulic servo pressure testing machines are used for specimens with higher age and higher strength compressive strength. The test results are recorded in Table 6.

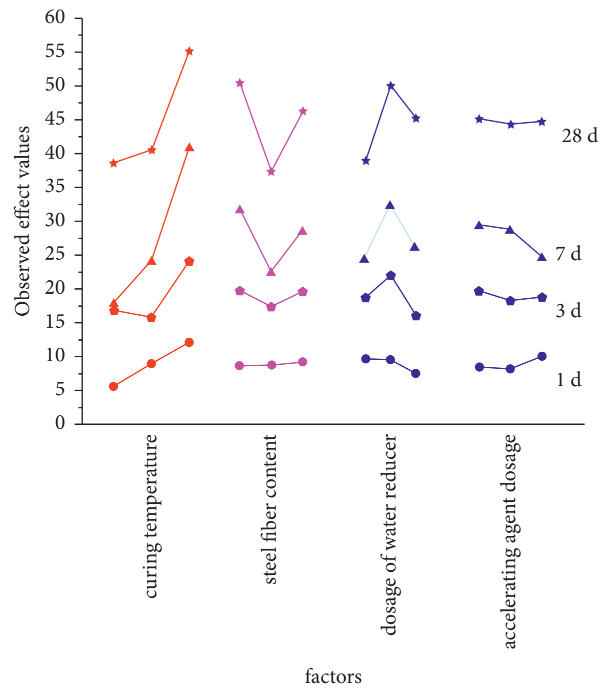

Figure 2: Effect curve fluctuation.

4.2. Analysis of Experiments Result. The test results in Table 6 were analyzed in turn using methods such as the intuitive analysis table, range, Pearson's correlation coefficient, and analysis of variance. See Table 3 for visual analysis.

It can be seen from Table 3 that the above four factors affect the compressive strength of concrete at one-day age in descending order: curing temperature > water reducing agent content > accelerating agent content > steel fiber content; for 3 days: curing temperature > water reducing agent content > steel fiber content > accelerator content; for 7 days: curing temperature > steel fiber content > water reducing agent content > quick-setting agent content; and for 28 days: curing temperature > steel fiber content > water reducing agent content > quick-setting agent content; the effect of water reducing agent is much smaller than other factors.

According to the observation value K_{ji} in Table 3, the effect curve of each factor on the compressive strength of concrete at different ages is drawn, as shown in Figure 2.

Correlation is a nondeterministic relationship, and the correlation coefficient is a measure of the degree of linear correlation between variables. Karl Pearson proposed the concept of correlation coefficient: assuming that X and Y are two random variables, σ_{xy} and σ_y represent the standard deviations of X and Y, respectively, σ_{xy} represents the covariance of X and Y, and the definition of Pearson correlation coefficient is $\rho = \sigma_{xy}/\sigma_x\sigma_y$. If the sample data of X and Y are $x_1, x_2, \ldots, x_n$, the correlation coefficient r of Pearson's sample is

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}}. \quad (2)$$

In (2), $\overline{x}$ and $\overline{y}$ represent the sample mean values of X and Y, respectively. The value of the correlation coefficient r is between −1 and 1; when $r < 0$, the two variables are negatively correlated, when $r > 0$, the two variables are positively correlated; when $r_{XY} = 0$, the variables X and Y are not correlated; $r_{XY} = -1$ or 1, X and Y are completely

Table 7: The compressive strength of concrete specimens is correlated with various factors.

Age of concrete	Correlation coefficient of compressive strength and various factors			
	Curing temperature	Steel fiber content	Water reducing agent content	Accelerating agent content
1	0.9999	0.9038	−0.8831	0.7859
3	0.8036	−0.0393	−0.4471	−0.6483
7	0.9672	−0.3306	0.2110	−0.9287
28	0.9143	−0.3148	0.5687	−0.57

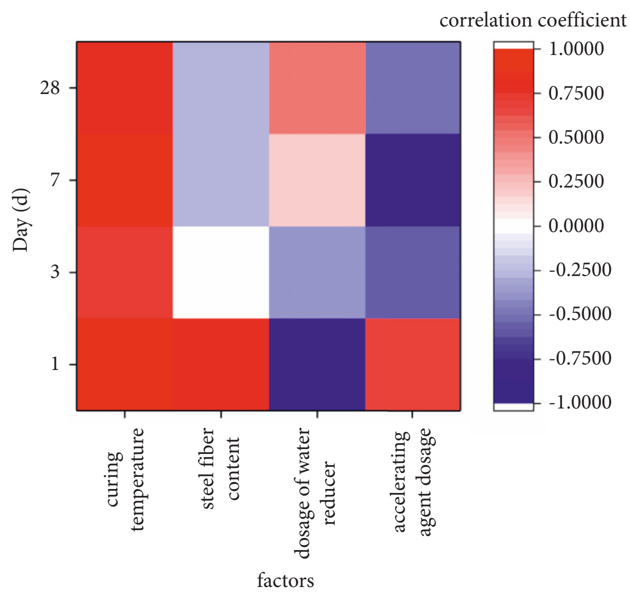

Figure 3: The compressive strength of concrete specimens is correlated with various factors.

correlated, and there is a linear functional relationship between X and Y; $0 < |r| < 1$ means that the two variables have a certain degree of linear correlation, and $|r|$ closer to 1 means the closer the linear relationship between the two variables, the closer $|r|$ is to 0, the weaker the linear relationship between the two variables; $|r_{XY}|>0.8$ is highly correlated; $0.8>|r_{XY}|>0.3$ is moderately correlated; and $|r_{XY}|<0.3$ is a low degree of correlation. The observation value K_{ji} is used to investigate the correlation coefficients between the compressive strength of the concrete specimens at various ages and various factors, as shown in Table 7 and Figure 3.

It can be seen from Table 7 and Figure 3 that the curing temperature is highly positively correlated with the compressive strength of concrete at various ages; the amount of steel fiber added to the compressive strength of concrete changes from a high degree of positive correlation to a low degree of negative correlation as the age increases and then to a medium degree of negative correlation; the amount of water reducing agent has a negative correlation with the compressive strength of concrete as the concrete age increases, from a high degree of negative correlation to a moderate negative correlation, then a low degree of positive correlation, and finally a moderate positive correlation. With the growth of concrete age, the content of accelerating agent changes from moderate positive correlation to moderate negative correlation, then to high negative correlation, and finally to moderate negative correlation.

In order to investigate whether the effect of each factor is significant at each level, the analysis results of Table 3 above are analyzed according to the different ages of concrete. "(*)", "*", and "**", respectively, indicate that the test result at the significance level $\alpha = 0.10$, 0.05, 0.01 rejects the null hypothesis; that is, the influence of this factor on the test result is more significant, significant, and extremely significantly. Checking the table shows that $F_{0.90}(2,2) = 9.00$, $F_{0.95}(2,2) = 19.00$, and $F_{0.99}(2,2) = 99.00$. It can be seen from Table 3 that the steel fiber content of 1-day-old concrete has little effect, and it is used as the error column of Table 8 for analysis of variance and significance test.

It is not difficult to see from Table 8 that the curing temperature has an extremely significant impact on the 1-day strength of steel fiber concrete mixed with water reducing agent and quick-setting admixture, and the effects of the content of water reducing agent and quick-setting admixture are both more significant. Since the amount of quick-setting admixture had the smallest sum of square deviations in the 3-day-old compressive strength test, it was used as the error column of Table 9 for analysis of variance and significance test.

It can be seen from Table 9 that the curing temperature has a significant impact on the 3-day compressive strength of the concrete, the water reducing agent content is more significant, and the steel fiber content is not significant. Since the sum of square deviations of the quick-setting admixture is the smallest in the 7d compressive strength test, it is taken as the error column, and the variance analysis is shown in Table 10.

It is found from Table 10 that the curing temperature has a significant effect on the 7-day strength of steel fiber concrete mixed with water reducing agent and quick-setting admixture, while the effects of steel fiber content, water reducing agent content, and quick-setting admixture content are not significant. Since the amount of quick-setting admixture has the smallest sum of square deviations in the 28 d compressive strength test, it is used as the error column of Table 11 for variance analysis and significance test.

It can be seen from Table 11 that curing temperature, steel fiber content, and water reducing agent content have extreme significant effects on the 28-day strength of concrete.

5. Scanning Results of Concrete Microstructure

The 28-day-old coagulation test block was dehydrated by anhydrous alcohol and sent to the Yunnan Analysis and Testing Center for electron microscope scanning, and the degree of hydration reaction was analyzed according to the

Table 8: Table of variance analysis of compressive strength of 1-day-old concrete specimen.

Type	Deviation sum of squares	Degree of freedom	Analysis of variance	Significance
Curing temperature	7.088	2	105.791	**
Steel fiber content	0.067	2	1.000	
Water reducing agent content	1.015	2	15.149	(*)
Accelerating agent content	0.71	2	10.892	(*)
Error	0.067	2		

Table 9: Table of variance analysis of compressive strength of 3-day-old concrete specimen.

Type	Deviation sum of squares	Degree of freedom	Analysis of variance	Significance
Curing temperature	13.604	2	36.570	*
Steel fiber content	1.189	2	3.196	
Water reducing agent content	5.948	2	15.989	(*)
Accelerating agent content	0.372	2	1.000	
Error	0.372	2		

Table 10: Table of variance analysis of compressive strength of 7-day-old concrete specimen.

Type	Deviation sum of squares	Degree of freedom	Analysis of variance	Significance
Curing temperature	96.632	2	21.669	(*)
Steel fiber content	14.631	2	3.386	
Water reducing agent content	11.527	2	2.668	
Accelerating agent content	4.321	2	1.000	
Error	4.321	2		

Table 11: Table of variance analysis of compressive strength of 28-day-old concrete specimen.

Type	Deviation sum of squares	Degree of freedom	Analysis of variance	Significance
Curing temperature	54.203	2	564.615	**
Steel fiber content	29.986	2	312.254	**
Water reducing agent content	20.241	2	210.854	**
Accelerating agent content	0.096	2	1.000	
Error	0.096	2		

microstructure. The scanning structure of each group of samples is shown in Figure 4.

In Figures 4(a) to 4(i) are taken from the test blocks of the first to ninth groups, so Figures 4(a)–4(c) are the microstructure of the concrete cured at 0 °C for 28 days, and the curing temperature of Figures 4(d)–4(f) samples is 6°C; the curing temperature of Figures 4(g)–4(i) samples is 12°C. It can be seen that the temperature has a more obvious influence on the hydration reaction of concrete. Under 0°C curing, the concrete hydration reaction is slow, and the hydration products are mainly "needle." The hydration products of this structure make the concrete have more microscopic voids and make the cementing force between the concrete aggregates relatively weak. Under 6°C curing, the hydration reaction is more sufficient than that at 0°C, which not only produces "needle" hydration products, but also produces some "flocculent" hydration products. The joint action of the two results in a strong bond between the concrete aggregates, which makes the compressive strength of the concrete test blocks higher under curing 6°C. Under the curing condition of 12°C, the concrete produces a large amount of "needle-like" hydration products, which accumulate into "flocculent" products, which not only reduces the pores between concrete aggregates, but also increases the bonding force between the aggregates. The concrete test block has greater compressive strength under the curing condition of 12°C than that under the curing condition of 0°C and 6°C.

Limited by the size of the scanned sample and the difficulty of production, the results of the cementation of steel fiber and concrete aggregate were not scanned. Existing scanning results did not show the influence of water reducer and accelerator on the microstructure, and the influence of accelerator on the microstructure of concrete is also related to the degree of vibration during sample preparation.

6. Discussion

6.1. The Influence of Various Factors on the Workability of the Mixture. Since the function of water reducing agent is to improve the workability of concrete mixture, analysis of variance also shows that it has a significant influence on the slump and spread of concrete mixture, so we will not discuss the water reducing agent in depth here.

The temperature of the mixture and the amount of steel fiber do not have a significant effect on the workability of the

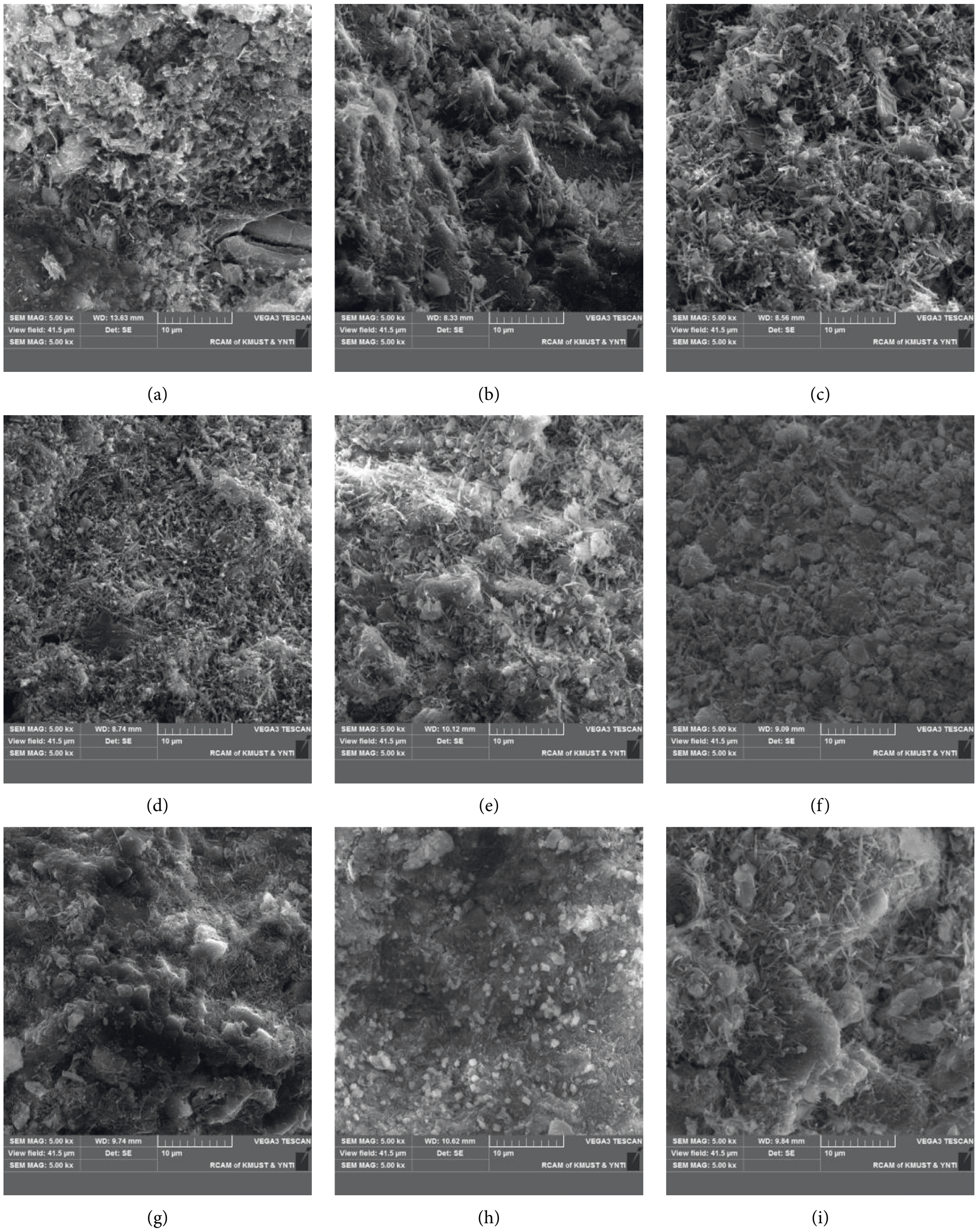

Figure 4: Concrete microstructure at 28 days.

concrete mixture. Temperature will affect the movement of water molecules, but in the production practice, the temperature change is small, which can neither make the water molecules move violently due to boiling nor freeze the water molecules, so the impact on the workability of the mixture is limited. In the actual production process, the hydration of a larger volume of cement will release heat so that the temperature of the mixture will not be too low. During the field investigation, it was also found that the concrete mixture poured from the tanker had a temperature of 30–40°C. Therefore, it can be considered that the temperature of the mixture will not have a significant effect on the workability of the mixture.

The amount of steel fiber is relatively small compared to the amount of sand and gravel. Length of steel fiber is only 2 to 3 cm, the diameter is less than 1 mm, and the surface is smooth, and the mass of a single steel fiber is less than 1 g. In a mixture with water and cement, even though it is hook-shaped, it is still in a suspended state. Therefore, it does not have a significant impact on the workability of the mixture.

6.2. The Influence of Various Factors on the Compressive Strength of Concrete Test Blocks. The effect of curing temperature on concrete specimens should be analyzed according to three conditions. The first case is that the temperature is too low (<0°C), the second case is within the normal temperature range of 0 ~ 80°C, and the third case is greater than 80°C. In the first case, temperature not only affects the rate of cement hydration reaction in the concrete, but may also cause the free water in the concrete that has not participated in the hydration reaction to be frozen. The volume expansion of free water after freezing destroys the structure of cementing material produced by cement hydration. In this case, the lower the temperature, the lower the hydration reaction rate, the higher the degree of free water freezing, the greater the volume expansion, and the lower the compressive strength of the concrete specimen. In the second case, the temperature increase will accelerate the cement hydration reaction, but it will not cause the moisture in the concrete to dissipate quickly, thus ensuring that the cement hydration reaction is relatively sufficient, thus accelerating the formation of the compressive strength of the concrete specimens. This ensure the later strength of concrete. The third case is not common and is not within the scope of this study and will not be discussed here.

The influence of age on concrete strength depends on the degree of cement hydration reaction. As mentioned above, the degree of cement hydration reaction depends on the rate of hydration reaction and the adequacy of the materials required for the hydration reaction. By adjusting the factors that affect the hydration reaction rate and the amount of materials, the time required for the concrete to reach the design strength can theoretically be adjusted. Therefore, the age of concrete is not consistent with the degree of hydration reaction in concrete, which is not enough to accurately reflect the degree of hydration reaction.

The amount of water reducing agent has a greater impact on the early strength of concrete. Before the concrete is formed, the water reducing agent may affect the fluidity of the water, cement particles, and fine aggregates in the concrete and then affect the porosity of the concrete, thereby affecting the compressive strength of the early concrete. With the growth of age, the cementation material in concrete gradually increases, which hinders the movement of water and fine particles, and inhibits the effect on the growth of the strength of water reducing agent concrete.

Steel fiber mainly connects concrete aggregates through cementing substances. The early concrete hydration reaction is not sufficient, and the connection effect of steel fiber is limited. As time goes by, the fuller the concrete hydration reaction, the more the amount of cementing material produced, and the more obvious the connection effect played by the steel fiber, so it has a beneficial effect on the compressive strength of the concrete. Therefore, within the range set by the experiment, the steel fiber content has less influence on the early strength of concrete and greater influence on the later strength of concrete.

Accelerators mainly accelerate concrete forming, and their principles are not discussed here. Accelerators have a certain effect on the early strength of concrete, mainly by accelerating the setting of concrete and reducing the fluidity of water and fine particles in the concrete, thereby affecting the porosity of the concrete, and then the porosity has an impact on the strength of the concrete. In the case of shotcrete support, the concrete needs to be formed as soon as possible, which may lose part of the concrete strength. In actual construction operations, attention should be paid to the selection of sprayed concrete equipment. Larger spraying pressure should reduce the porosity of the concrete, thereby having a beneficial effect on the strength of the concrete and ultimately offsetting the adverse effects of the incorporation of accelerators on the strength of the concrete.

7. Conclusion

This paper studies the effects of mixing temperature, water reducing agent, and steel fiber content on slump and expansion of concrete mixture, in addition to the effects of age, curing temperature, steel fiber content, water reducing agent content, and accelerating agent content on compressive strength of concrete and mainly draws the following conclusions:

(1) In the concrete mixture, the greater the amount of water reducing agent, the greater the slump and expansion of the mixture; the temperature of the mixture and the amount of steel fiber have little effect on the slump; the production operation is adjustable. The amount of water reducing agent improves the workability of the concrete mixture.

(2) The curing temperature has a significant effect on the compressive strength growth of concrete specimens. The higher the curing temperature in the range of 0–20°C, the more concrete hydration products, the higher the degree of reaction, and the faster the strength growth.

(3) The age of concrete has a greater impact on the strength of concrete. The older the age of concrete, the greater the compressive strength of concrete.

(4) The content of water reducing agent and accelerator has a significant effect on the early strength of concrete, but has a small effect on the later strength; the content of steel fiber has a small effect on the early strength of concrete, but has a greater impact on the later strength.

In high-cold areas or areas with large temperature differences between day and night, special attention should be paid to heat preservation during the maintenance of the concrete supporting structure.

Data Availability

The experimental data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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