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Orthogonal Experimental Study on the Ratio of Similar Materials of Coal Body

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Abstract: According to the coal samples collected from Zhaogu No.2 Coal Mine as raw coal samples, the similar materials of coal body were studied by using river sand, pulverized coal, Portland cement and calcium carbonate. The orthogonal test method of four factors (bone glue ratio, aggregate ratio, rubber ratio, water mixing rate) and three levels was used to obtain the physical and mechanical parameters such as density, uniaxial compressive strength, elastic modulus, cohesion, internal friction angle and tensile strength of coal similar materials. The range analysis method was used to obtain the key influencing factors and variation rules of the physical and mechanical properties of coal similar materials. Finally, the method of multiple linear regression analysis was used to obtain the similar material ratio that was most consistent with the mechanical properties index of raw coal. The ratio of calcium carbonate: cement: river sand: coal powder: water = 1: 5: 0.9: 5.9: 3.2. The density error, compressive strength error, elastic modulus error and cohesion error of coal sample and raw coal are small, which proves that the similar material is similar to the mechanical properties of raw coal, and provides guidance for subsequent research.

Keywords: Orthogonal test; Coal similar materials; Ratio; Range analysis; Numerical simulation.

1. Introduction

Similar material simulation experiment is widely used in the field of mining engineering, and the selection of similar materials and ratios plays a decisive role in the success of the simulation experiment. As far as the topic of coal rock similar material ratio is concerned, scholars at home and abroad have done a lot of experiments and accumulated rich experience. Based on the experimental method of orthogonal test, Gong Yufei et al. prepared similar materials by using coal powder, sand and cement as raw materials for the test, and determined the optimal construction ratio of different geological structural units by comparison. Wu Botao et al. used barite powder, fine sand, gypsum, and laundry detergent as raw materials for preparation, and finally achieved the purpose of simulating surrounding rock. Jia Baoxin et al. used quartz sand, iron powder, gypsum, cement, retarder and water reducing agent as the main materials, and finally met the requirements of similar material model test of white sandstone. By summarizing the results of previous studies, it is found that although there are many methods for preparing similar materials, there are few studies on using specific mechanical parameters as indicators to formulate similar materials. Therefore, this paper takes the coal and rock of the working face of Zhaogu No.2 Coal Mine as the object, prepares similar materials with specific mechanical parameters, explores the ratio of similar materials closest to the mechanical properties of raw coal, and lays a foundation for subsequent model tests.

2. Mechanical Property Test of Raw Coal

2.1. Selection of raw coal

The raw coal is collected from the 11012 working face of Zhaogu No.2 Mine. The length of the working face is 167.5m, the advancing length is about 2050m, the buried depth of the coal seam is about 700m, and the dip angle is 3 ° ~ 9 °. It belongs to the near horizontal coal seam. The average coal thickness is 2.3m, the advancing speed of the working face is 4 ~ 5m / d, and the coal rock is relatively complete. The coal block was drilled, cored, cut and ground to make a standard sample with a diameter of 50 mm and a height of 100 mm and a diameter of 50 mm and a height of 25 mm, ensuring that the parallelism at both ends was within 0.05 mm. The basic physical parameters of coal samples are shown in Table 1.

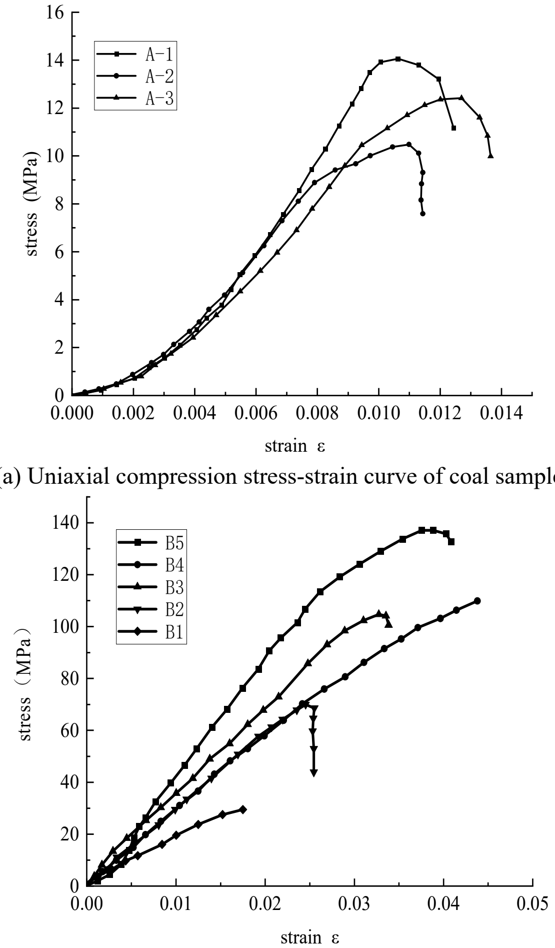
Table 1. Basic physical parameters of raw coal samples

Number	diameter /mm	height /mm	quality /g	crude density /g/cm^3
A-1	49.1	99.9	245.9	1.30
A-2	49.2	100.4	249.9	1.31
A-3	49.2	100.0	243.9	1.28
B-1	49.3	101.3	250.3	1.29
B-2	49.5	100.2	251.8	1.31
B-3	49.4	100.4	247.1	1.28
B-4	49.2	99.9	244.9	1.29
B-5	49.3	100.4	248.4	1.30
C-1	26.4	49.8	63.3	1.32
C-2	25.9	49.8	62.6	1.31
C-3	26.2	49.7	62.8	1.33

The uniaxial compression test, Brazilian splitting test and triaxial compression test of coal samples were carried out on the RMT-150B rock mechanics test bench. In the uniaxial compression test, displacement control was applied, and the loading rate was 0.005 mm / s until the coal sample was broken. The confining pressure was set to 5,10,15,20,25 MPa in the triaxial compression test, and the confining pressure was kept constant. The displacement control was applied at a loading rate of 0.01 mm / s until the specimen broke. There are three groups of uniaxial compression tests: A-1, A-2 and A-3. There are five groups of triaxial compression tests: B-1, B-2, B-3, B-4 and B-5. There are three groups of Brazilian splitting: C-1, C-2 and C-3.

2.2. Test result

The stress-strain curves of coal samples under uniaxial compression and triaxial compression are shown in Fig.1.In the uniaxial compression test, the peak compressive strength of raw coal is 14.31 MPa, 10.59 MPa and 12.58 MPa respectively, and the average compressive strength is 12.49 MPa.In the triaxial test, the peak stress strength of raw coal is 30.71 MPa, 70.45 MPa, 105.75 MPa, 111.99 MPa and 138.17 MPa respectively. The test results are shown in Table 2 and Table 3. In the table: ε_c represents the peak strain, σ_c represents the uniaxial compressive strength, E represents the elastic modulus, μ represents the Poisson 's ratio.



(a) Uniaxial compression stress-strain curve of coal sample

(b) Triaxial compression stress-strain curve of coal sample

Figure 1. Raw coal compression test curve

Table 2. Uniaxial compression test results of coal samples

Number	εc/10-3	σc/MPa	E/GPa	μ
A-1	12.06	14.31	2.14	0.30
A-2	11.57	10.59	1.62	0.30
A-3	13.62	12.58	1.60	0.27

Table 3. Triaxial compression test results of raw coal samples

Number	σ_3/MPa	σ_1/MPa	φ/°	c/MPa
B-1	4.99	30.71		
B-2	9.97	70.45		
B-3	15.00	105.75	43.4	3.21
B-4	19.98	111.99		
B-5	24.98	138.17		

Through table 2 and table 3, it can be seen that the elastic modulus of raw coal in group A is 2.14 GPa, 1.62 GPa and 1.60 GPa respectively, the average elastic modulus is 1.79 GPa, the Poisson 's ratio is 0.30,0.30,0.27 respectively, and the average value is 0.29. Compared with the results of triaxial test, it can be seen that the natural density, uniaxial compressive strength, elastic modulus, Poisson 's ratio, internal friction angle and cohesion of Zhaogu coal sample are 1.30 g / cm3,12.49 MPa, 1.79 GPa, 0.29,43.4 ° and 3.21 MPa respectively, and Zhaogu coal sample is medium hard coal.

3. Orthogonal Design

3.1. Orthogonal test design

In the fractional factorial design, orthogonal test was used for research. In the test, fine river sand and pulverized coal were selected as aggregates, and the particle sizes were in the range of 0.2-1.5mm and 0.5-2mm respectively. 32.5 Portland cement and light calcium carbonate were selected as cementing materials. Distilled water was selected as the test water. A total of 4 influencing factors were designed in the experiment, and 3 levels were designed for each influencing factor, as shown in Table 4. In the table, A represents the ratio of aggregate and binder quality ($m_{aggregate}$: m_{binder}), B represents the ratio of binder composition quality ($m_{calcium\ carbonate}$: m_{cement}), C represents the ratio of aggregate composition quality ($m_{river\ sand}$: $m_{pulverized\ coal}$), D represents the water mixing rate, that is, the ratio of water quality to aggregate and binder quality (m_{water}: ($m_{aggregate}$ + m_{binder})). According to the influencing factors and the number of their levels, 9 groups of similar material mix ratio test schemes were designed, as shown in table 5.

Table 4. Levels of each factor

Level	A (Bone glue ratio)	B (Rubber to material ratio)	C (Aggrega te ratio)	D (Water mixing ratio)/%
1	4:3	1:5	1:4	24
2	5:3	1:3	3:7	27
3	2:1	1:2	1:2	30

Table 5. Similar material orthogonal table

Test number	Bone glue ratio	Rubber to material ratio	Aggregate ratio	Water mixing ratio
1	1(4:3)	1(1:5)	1(1:4)	1(24%)
2	1(4:3)	2(1:3)	2(3:7)	2(27%)
3	1(4:3)	3(1:2)	3(1:2)	3(30%)
4	2(5:3)	1(1:5)	2(3:7)	3(30%)
5	2(5:3)	2(1:3)	3(1:2)	1(24%)
6	2(5:3)	3(1:2)	1(1:4)	2(27%)
7	3(2:1)	1(1:5)	3(1:2)	2(27%)
8	3(2:1)	2(1:3)	1(1:4)	3(30%)
9	3(2:1)	3(1:2)	2(3:7)	1(24%)

3.2. Specimen making and maintenance

The standard cylinder specimen is poured with detachable stainless steel mold, and the cube is poured with standard mold box. The relevant mold requires no obvious gap, the overall smooth and smooth, to ensure that the close does not leak. The details are as follows:

(1) Material preparation. The relevant raw materials are weighed according to the above ratio. Before adding water, the solid materials should be fully stirred evenly.

(2) Mold preparation. Clean the mold before pouring

similar materials, and brush a little lubricating oil to facilitate demoulding.

(3) Mixing pouring. Put the mixed material into the stirrer to stir slowly, add water, and then stir quickly for three minutes, so that the material is fully stirred evenly; then, the mixed material is poured into the mold, and the material is fully vibrated and compacted on the vibration table. When the material is poured, it should be slightly overflowed, because the material will shrink during the vibration.

(4) Demoulding and maintenance. Before the material is not finalized, the surface is scraped flat, standing for 24 hours after demoulding, in the indoor constant temperature curing 28 days, after the section is polished and smoothed, weighing and measuring the size.

The lack of corners during partial demolding needs to be re-supplemented to ensure that there are 3 samples in each group, and a total of 81 samples in 9 groups of tests.

3.3. Test results of mechanical properties of similar materials

The uniaxial compression and Brazilian splitting tests of similar materials were carried out by YNS300 universal testing machine, and the uniaxial compression and elastic modulus of similar materials were obtained. In the test, the loading speed is 0.005 mm / s, and the displacement loading method is adopted until the specimen is completely broken. A standard cylindrical specimen with a diameter of 50 ± 2mm and a height diameter of 2: 1 is used. Both ends of the specimen are smooth, and the unevenness deviation of the surface at both ends cannot exceed 0.05mm. The diameter deviation of any height section of the specimen cannot exceed 0.3mm, and the number of specimens in each group is not less than 3. Uniaxial compression tests were performed

The collected stress-displacement curve is shown in Fig.2.Each group selects a specimen with a better curve as a representative. From the diagram, it can be seen that the peak stress of the specimens is 16.98 MPa, 14.40 MPa, 8.09 MPa, 8.06 MPa, 11.58 MPa, 2.89 MPa, 5.17 MPa, 1.49 MPa and 3.14 MPa, respectively.

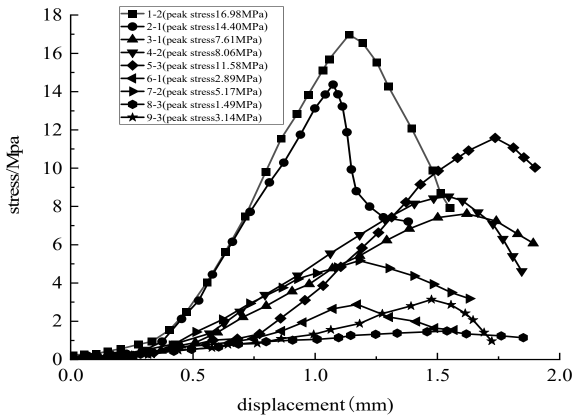


Figure 2. Stress-displacement curve of similar material

According to the relevant requirements of GB / T50266-2013 ' Engineering rock mass test method standard ', the similar materials of each group were tested respectively, and the corresponding physical and mechanical properties were obtained. The results are shown in Table 6 (Note: The test results of each group in the table are the average of the three samples).

Table 6. Orthogonal test results of similar materials

Number	density /(g/cm^3)	compressive strength /MPa	elastic modulus /GPa	tensile strength /MPa	angle of internal friction /°	force of cohesion / MPa
1	1.72	16.98	2.28	0.89	43.23	3.51
2	1.69	14.40	1.85	0.74	35.37	3.43
3	1.60	8.09	0.71	0.49	19.29	3.27
4	1.60	8.06	0.95	0.58	22.29	2.88
5	1.68	11.58	1.32	0.67	28.81	2.73
6	1.55	2.89	0.50	0.28	22.68	2.54
7	1.61	5.17	0.51	0.48	47.73	2.40
8	1.48	1.49	0.21	0.15	21.80	2.50
9	1.58	3.14	0.36	0.43	34.02	2.08

It can be seen from Table 6 that the first group of similar materials has the largest aggregate and the smallest water content. The results are the largest, the density is 1.72 g / cm3, the minimum is 1.48 g / cm3, the compressive strength is 16.98 MPa, the minimum is 1.49 MPa, the elastic modulus is 2.28 GPa, the minimum is 0.21 GPa, the tensile strength is 0.89 MPa, the minimum is 0.15 MPa, the friction angle is 43.23 °, the minimum is 19.29 °, the cohesion is 3.51 MPa, and the minimum is 2.08 MPa.

4. Ensibility Analysis of Influence Factors

4.1. Density range analysis

The orthogonal test results were analyzed by range analysis. The average value of the experimental results under the same level of factors is taken, and the maximum value is subtracted from the minimum value as the range. If the difference is small, it indicates that the experimental results have no obvious effect on the results.

Taking density as the research object, the average value and range of the four factors are given in table 7 below. It can be seen from Table 7 that the maximum range is A factor 0.112, and the minimum is C factor 0.048. It shows that factor A is the main factor, and the sensitivity of each factor is A > B > D > C.

Table 7. Density range analysis (g / cm3)

Factor / level	Level 1	Level 2	Level 3	Range R
A	1.671	1.611	1.558	0.112
B	1.642	1.622	1.574	0.068
C	1.593	1.624	1.632	0.048
D	1.663	1.625	1.562	0.099

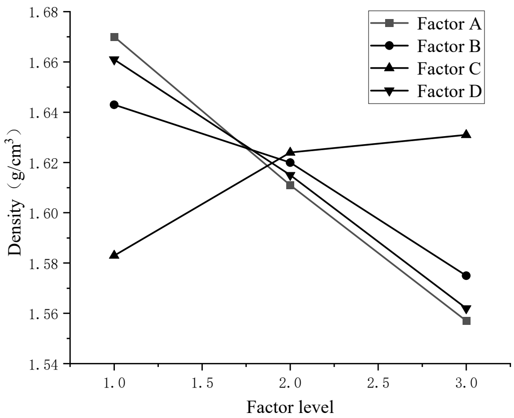


Figure 3. Intuitive analysis of density influencing factors

Make an intuitive analysis chart through the above table, as shown in Figure 3. The analysis shows that the maximum difference between the mass ratio of aggregate to cementing material and the water content is 0.112, which is the main factor determining the density. The density of group A decreased from 1.671 g / cm3 to 1.558 g / cm3, and that of group B decreased from 1.642 g / cm3 to 1.574 g / cm3. With the increase of the proportion, the density of group C increased from 1.593 g / cm3 to 1.632 g / cm3, and the density of group D decreased from 1.663 g / cm3 to 1.562 g / cm3.

4.2. Range analysis of uniaxial compressive strength

Taking the uniaxial compressive strength as the object, the range analysis is given in the following table. It can be seen from Table 8 that the mass ratio of aggregate to cementing material is the main factor determining the uniaxial compressive strength, the maximum range is 9.88, and the sensitivity of each factor is A > B > D > C.

Table 8. Range analysis of uniaxial compressive strength (MPa)

Factor / level	Level 1	Level 2	Level 3	Range R
A	13.16	7.53	3.28	9.88
B	10.06	9.17	4.71	5.36
C	7.13	8.55	8.28	1.41
D	10.57	7.51	5.88	4.68

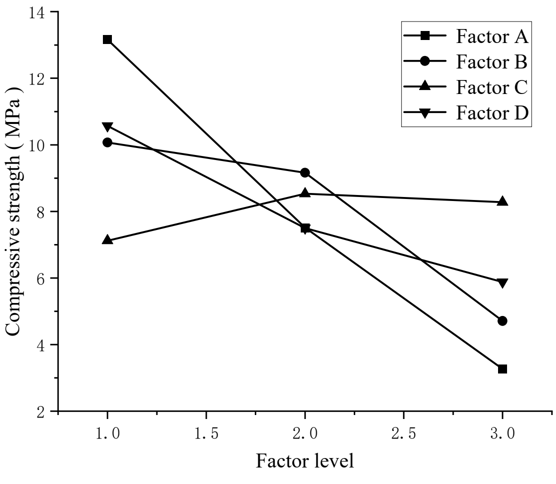


Figure 4. Visual analysis diagram of influencing factors of uniaxial compressive strength

According to table 8, the visual analysis diagram of the influencing factors of compressive strength is drawn as figure 4. It can be found that the uniaxial compressive strength decreases with the increase of A ($m_{aggregate}$: m_{binder}), B ($m_{calcium\ carbonate}$: m_{cement}), D (m_{water}: ($m_{aggregate}$ + m_{binder})), and increases first and then decreases with the increase of C ($m_{river\ sand}$: $m_{pulverized\ coal}$). Among them, A factor, B factor and D factor have a greater impact on the uniaxial compressive strength of similar materials, while C factor has a smaller impact.

4.3. Elastic modulus range analysis

Taking the elastic modulus as the object, the mean and range of each factor are given in table 9 below. It can be seen from the data in the table that the factor A has the largest range, that is, the mass ratio of aggregate to cementing material is the main influencing factor to determine the elastic modulus, and the sensitivity of each factor is A > B > D > C.

Table 9. Range analysis of elastic modulus (GPa)

Factor / level	Level 1	Level 2	Level 3	Range R
A	1.61	0.92	0.36	1.26
B	1.25	1.13	0.52	0.72
C	1.00	1.05	0.85	0.30
D	1.32	0.95	0.62	0.69

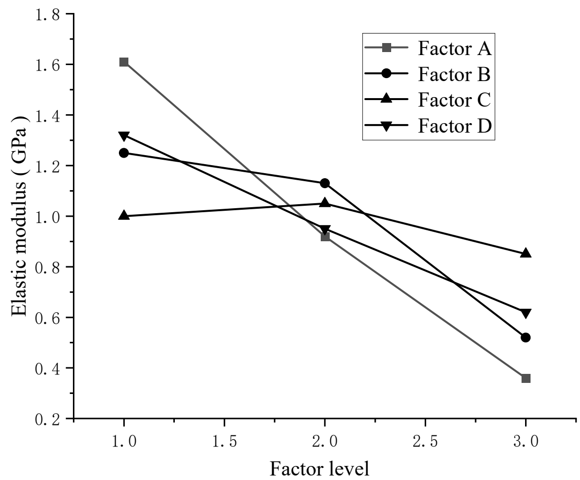


Figure 5. Intuitive analysis of influencing factors of elastic modulus

According to Table 9, the intuitive analysis of the influencing factors of elastic modulus is shown in Fig.5.It can be found that the elastic modulus decreases significantly with the increase of A (m aggregate: m cementing agent), and the influence range is the largest. It decreases with the increase of D (m water: (m aggregate + m binder)) and B (m calcium carbonate: m cement), with the maximum range of 1.26 and the minimum range of 0.30.

4.4. Cohesion range analysis

Taking cohesion as the object, the following table 10 gives the average value and range of each of the four factors. It can be seen that the maximum range is 1.06 and the minimum range is 0.04, indicating that factor A is the main influencing factor, and the effect of factor C is not obvious. The sensitivity of each factor is A > B > C > D.

Table 10. Cohesion range analysis (GPa)

Factor / level	Level 1	Level 2	Level 3	Range R
A	3.40	2.72	2.33	1.06
B	2.94	2.89	2.65	0.3
C	2.87	2.80	2.81	0.04
D	2.78	2.80	2.88	0.1

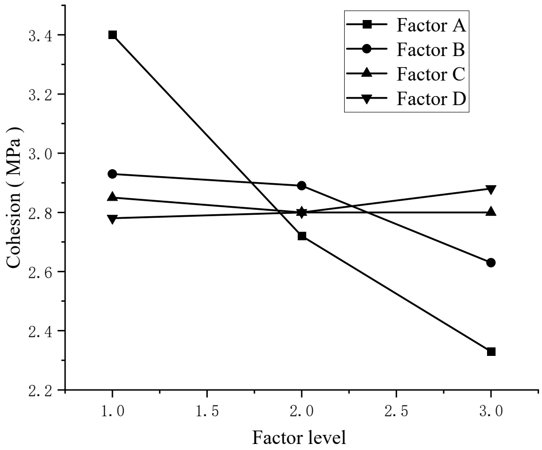


Figure 6. Intuitive analysis of influencing factors of cohesion

Through Table 10, the intuitive analysis of each factor is shown in Figure 6. It can be seen from the figure that factor A is the main factor. The more factors B and C account for, the smaller the cohesion decreases from 2.94 to 2.65, from 2.87 to 2.81, but the change is not obvious.

4.5. Analysis of internal friction angle range

Taking the internal friction angle as the object, the mean and variance of each level of the four factors are given in Table 11. From the table, it can be seen that the sensitivity of the internal friction angle factor of the material is: D ≈ B > A > C. The influence of B and D factors on the internal friction angle is roughly equal. The minimum range of factor C is 3.43.

Table 11. Internal friction angle range analysis (°)

Factor / level	Level 1	Level 2	Level 3	Range R
A	33.71	25.60	34.53	8.92
B	37.75	28.66	25.33	12.52
C	35.35	35.26	31.94	3.43
D	35.35	35.26	21.13	14.32

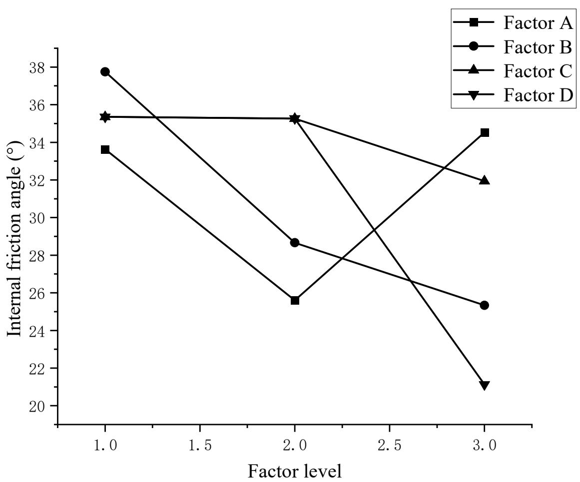


Figure 7. Intuitive analysis of influencing factors of internal friction angle

Through the above table, the visual analysis diagram of each factor is made, such as figure 6. From the diagram, it can be seen that B and D factors change significantly, and the differences are 12.52 and 14.32, respectively, indicating that B and D are the main factors. The internal friction angle of A factor is 33.71,25.60 and 34.53, respectively, showing a trend of decreasing first and then increasing. The more the proportion of C factor, the internal friction angle has been decreasing.

4.6. Tensile strength range analysis

Taking the tensile strength as the research object, the following table 12 reflects the range. The influence of each factor on the tensile strength is: A ≈ B > D > C, and the factor C is the minimum range of 0.07.

Table 12. Range analysis of tensile strength (MPa)

Factor / level	Level 1	Level 2	Level 3	Range R
A	0.73	0.51	0.34	0.36
B	0.64	0.76	0.41	0.36
C	0.53	0.58	0.56	0.07
D	0.67	0.50	0.41	0.26

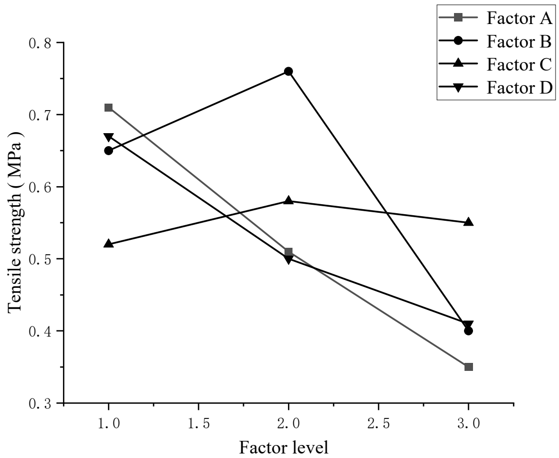


Figure 8. Intuitive analysis of influencing factors of tensile strength

Make an intuitive analysis of various factors through the above table, as shown in Figure 8. It can be seen from the figure that factors A and B are the main factors, and the changes are obvious, which decrease from 0.73 MPa to 0.34 MPa and from 0.64 MPa to 0.41 MPa, respectively. The C factor increases first and then decreases, from 0.53 MPa to 0.56 MPa, but the change is not obvious. The proportion of D factor increases, and the tensile strength of the material decreases all the time.

5. Multiple Linear Regression Analysis

Based on the experimental results of orthogonal design, A (m aggregate: m binder), B (m calcium carbonate: m cement), C (m river sand: m pulverized coal) and D (m water: (m aggregate + m binder)) were used as independent variables, which were represented by x1, x2, x3 and x4, respectively. The density, uniaxial compressive strength, tensile strength, elastic modulus and cohesion were used as dependent variables, and the multiple linear regression analysis was carried out by Matlab. The linear regression equation of density is as follows:

$$E(\rho) = -0.17x_1 - 0.23x_2 + 0.20x_3 - 1.65x_4 + 2.34 \quad (1)$$

Similarly, the linear regression equation of uniaxial compressive strength is:

$$E(R_C) = -14.83x_1 - 18.24x_2 + 5.28x_3 - 78.07x_4 + 57.98 \quad (2)$$

Similarly, the linear regression equation of elastic modulus:

$$E(E) = -1.87x_1 - 2.46x_2 - 0.42x_3 - 11.56x_4 + 8.22 \quad (3)$$

Similarly, the linear regression equation of cohesion:

$$E(c) = -1.61x_1 - 1.02x_2 - 0.234x_3 - 1.77x_4 + 5.47 \quad (4)$$

The order of fitting degree of the above regression equation is: r12 = 0.996, r22 = 0.9682, r32 = 0.964, r42 = 0.9714. The results show that the maximum residuals of the predicted values of density, uniaxial compressive strength, elastic modulus and cohesion model are only 0.012, -1.490, -0.244 and 1.4671, respectively, indicating that the established regression equation has a good fitting effect. It is reasonable to use this model to calculate the mix ratio of similar materials consistent with the simulation index.

6. Calculation Ratio and Test Verification

According to the similarity principle, the simulated index values ρ = 1.64g / cm3, σc = 12.50MPa, E = 1.78GPa, C = 3.21 are substituted into Formula 1-4, and solved by Gauss elimination method in MATLAB program. The ratio of similar material samples is: a = 1.333, b = 0.252, c = 0.156, d = 28.1 %, that is, calcium carbonate: cement: river sand: pulverized coal: water = 1: 5: 0.9: 5.9: 3.2. Through the ratio of similar materials, the simulation index of similar materials after testing is compared with the mechanical properties of raw coal, as shown in Table 14.The density error is 0.02g / cm3, the compressive strength error is 0.67 MPa, the elastic modulus error is 0.07 GPa, the cohesion error is 0.35 MPa, the internal friction angle error is 6.4 °, and the tensile strength error is 0.08.There is a small gap between the basic mechanical properties of similar materials and raw coal, which meets the test requirements.

Table 13. Residuals of linear regression model

Number	Density $\delta\rho$/MPa	Compressive strength δC/MPa	Elastic modulus δE/ GPa	Cohesive force δc/ MPa
1	-0.004	-0.168	-0.077	0.642
2	0.011	1.074	0.245	-2.376
3	-0.005	-0.214	-0.105	1.210
4	-0.001	-0.395	-0.010	-0.584
5	-0.001	0.497	0.027	1.467
6	-0.002	-1.489	-0.142	0.165
7	-0.002	-1.062	-0.138	0.251
8	0.002	1.348	0.133	0.354
9	0.001	0.409	0.068	-1.129

Table 14. Comparison of similar material samples and raw coal parameters

Classification	Density	Compressive strength	Elastic modulus	Cohesive force	Internal friction angle	Tensile strength
Raw coal	1.64g/cm3	12.50MPa	1.78GPa	3.21MPa	43.4°	0.73 MPa
Similar material samples	1.62g/cm3	11.83MPa	1.71GPa	2.86MPa	37°	0.65 MPa

7. Conclusion

(1) Based on the raw coal samples collected from Zhaogu No.2 Mine, the basic mechanical parameters were measured and a series of mechanical tests were carried out to determine the changes of uniaxial compressive stress, triaxial compressive stress, elastic modulus, compressive strength and Poisson 's ratio parameters. The density, uniaxial compressive strength, elastic modulus, cohesion, internal friction angle and tensile strength of similar materials were selected as simulation indicators for comparison. The orthogonal test was selected as the test method, the range analysis was selected as the analysis method, and finally the multivariate analysis method was used for verification.

(2) According to the range sensitivity analysis, the key factors affecting the density, uniaxial compressive strength, elastic modulus, cohesion and tensile strength of media similar materials are ($m_{aggregate}$: m_{binder}). With the increase of the ratio of ($m_{aggregate}$: m_{binder}), the above indexes all decrease. The influence of ($m_{calcium\ carbonate}$: m_{cement}) on the above indexes is second. With the increase of the ratio, the decreasing trend of the above indexes is slightly slower. ($m_{river\ sand}$: $m_{pulverized\ coal}$) has the least influence on the above factors, but with the increase of its ratio, the influence on the density and tensile strength of similar materials gradually increases ; finally, m_{water} : ($m_{aggregate}$ + $m_{cementing\ agent}$), with the increase of its ratio, the influence degree of the above indexes decreases, except for the influence on cohesion ; the key factors affecting the internal friction angle are mainly ($m_{calcium\ carbonate}$: m_{cement}) and (m_{water} : ($m_{aggregate}$ + m_{binder})). With the increase of the ratio, the internal friction angle decreases gradually. With the increase of the ratio of ($m_{aggregate}$: m_{binder}), the internal friction angle increases first and then decreases. The increase of the ratio of ($m_{river\ sand}$: $m_{pulverized\ coal}$) has little effect on the internal friction angle.

(3) Finally, the method of multiple linear regression

analysis was used to obtain the similar material ratio that is most consistent with the mechanical properties index of raw coal. The ratio of calcium carbonate: cement: river sand: pulverized coal: water = 1: 5: 0.9: 5.9: 3.2. The density error between the similar material prepared by this ratio and the raw coal is 0.01g / cm3, the compressive strength error is 0.66 MPa, the elastic modulus error is 0.08 GPa, and the cohesive force error is 0.34 MPa. The error is small and similar to the mechanical properties of raw coal samples.

References

[1] Huo Chao, Liu Tianji, Fan Bin, et al. Research on the layout of coal resources exploration and development in China under the background of double carbon [J]. Geological review, 2022,68 (03): 938-944.

[2] Li Huaizhen, Li Xuehua, Zhong Zhaohui, etc. Experimental study on slip debonding and mechanical properties analysis of coal-rock anchoring system [J]. Journal of Mining and Safety Engineering, 2017,34 (06): 1088-1093.

[3] Jiang Wan, Wei Jianping, Xu Xiangyu. Analysis of flow field structure of excavation roadway based on similarity theory [J]. Chinese Journal of Safety Science, 2018,28 (08): 142-148.

[4] Zhong Kaiqi, Xiao Yang, Lu Xing, etc. Orthogonal experimental design and range analysis of TPCT extraction from coal fire thermal energy [J]. Chinese Journal of Safety Science, 2021,31 (09): 135-141.

[5] Gong Yufei, Zhu Guowei, Jiang Yupu, et al. Experimental study on the ratio of similar materials in different geological structures of coal seams [J]. Journal of Mining Science, 2022,7 (03): 267-274.

[6] Jia Baoxin, Yuan Wenya, Ma Chaoyi, etc. Proportioning test and characteristic analysis of similar materials of white sandstone [J]. Underground space and engineering, 2022,18 (02): 503-512.

[7] Hou Dinggui, Yang Xiaojie, Wang Jiamin. Monitoring technology and application of roadway surrounding rock instability [J]. Journal of Mining and Safety Engineering, 2019,36 (01): 122-130.

[8] Wang Hongru, Zhao Mi, Zhong Zilan, etc. Study on similar materials for quasi-static scale test of cross-fault tunnel [J]. Engineering Mechanics, 2022,39 (06): 21-30 + 145.

[9] Dong Jinyu, Yang Jihong, Yang Guoxiang, etc. Experimental study on mix proportion of similar materials in model test based on orthogonal design [J]. Coal Journal, 2012,37 (1): 44-49.

[10] Hou Dinggui, Yang Xiaojie, Wang Jiamin. Monitoring technology and application of roadway surrounding rock instability [J]. Journal of Mining and Safety Engineering, 2019,36 (01): 122-130.

[11] Huang Yanhua, Yang Shengqi, Liu Xiangru. Experimental and numerical studies on mechanical properties of rock-like materials [J]. Experimental mechanics, 2014,29 (2) : 239-249.

[12] Wang Dequan, Zhang Chao, Zhang Kaicheng, Kang Mingchao, Guo Xueting. Axial force analysis of full-length resin bolt under pull-out load [J]. Nonferrous metals (mine part), 2021,73 (03) : 15-21.

[13] Wang Hongru, Zhao Mi, Zhong Zilan, Zhang Xiangyang, Zhao Xu, Du Xiuli. Study on similar materials for quasi-static scale test of cross-fault tunnel [J]. Engineering Mechanics, 2022,39 (06) : 21-30 + 145.

[14] Xiao Tongqiang, Li Huaizhen, Zhi Guanghui. Similar model test on stability of surrounding rock in deep thick top coal roadway [J].Coal Journal, 2014,39 (06) : 1016-1022.

[15] Yao Qiangling, Wang Weinan, Meng Guosheng, Li Xuehua, Wang Xiangyu, Zhao Min. Experimental study on stress characteristics of anchorage section of resin bolt with different anchorage length [J]. Journal of Mining and Safety Engineering, 2019, 36 (04) : 643-649.