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Experimental study on mechanical properties and proportioning process optimization of the strengthening material Clay reinforced by Caragana

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***Abstract*— In this paper, the conventional mechanical properties of reinforced composites Clay reinforced by Caragana are systematically studied. The experiment was in a complete factorial design, water content and compaction constant, Caragana reinforcement length and reinforced ratio as experimental factors, the mechanical properties of specimens under tensile, compressive, bending, shear and torsion forms are measured. The variation trend of strength of Clay reinforced by Caragana with the length and the rate of Caragana are analyzed. And through the SAS software, the optimum reinforcement parameters of the reinforcing material were determined. The test results showed that the optimum interval of the conventional mechanical properties of the material Clay reinforced by Caragana is very close,:the Caragana reinforcement length between 4 and 4.75mm, reinforced ratio between 0.2% and 0.25%; The optimum technology is the length 4~4.75mm and reinforced ratio 0.25%. The results provide the basis for the technological parameters of the strengthening material reinforced Caragana.**

***Index Terms*— Caragana; Clay base; strengthening process; mechanical properties**

I. INTRODUCTION

Caragana not only has obvious effect of windbreak and sand fixation [1], but also has good mechanical properties for its branches as wood materials [2]. This property make it can be used as a good reinforcing material for soil base composite as the basic material. Reinforced composites have been applied in building reinforcement[3], corrosion resistant components[4], functional / intelligent materials[5] and so on, but usually it is glass fiber, carbon fiber, aramid fiber and other chemical fiber polymer, as well as corn stalk, wheat straw, hemp sticks and other annual plant fiber that have been used as reinforcement material, the purpose of this study is to explore the application of Caragana as wood fiber reinforced material in construction industry.

The structure of the earth wall is widely used in northern area of China [6], scholars mainly focus on the study of its compressive properties[7, 8], and little research on other mechanical properties. However, under certain special working conditions, it is not uncommon for the soil structure to be damaged by other forms of deformation leading the damage of the whole structure. Destruction of earth rock dam on arch effect[9], cracking of soil under the dry environment[10] is all caused by the tensile stress. In earthquake disaster, the structure of the building is not only affected by shearing, but also by the torsion effect around the center of rigidity [11]. Therefore, it has important engineering significance to study the mechanical properties of soil structure systematically.

Based on the existing specifications and other scholars' research on the mechanical properties of materials, the methods are optimized corresponding the characteristics of the materials studied in this paper, studying the mechanical properties of soil reinforced with Caragana under the tensile, compressive, bending, shear and torsion forms deformation, and on this basis the proportioning process is optimized to guide its application in engineering practice.

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II. MATERIALS AND METHODS

1.1 Test material

The soil samples used in this experiment are clay samples in Lantau Peak District, Taigu County, Shanxi Province, China. Samples are prepared before making the sample. After cleaning, grinding, screening and drying, the basic physical indexes are shown in Table 1.

The material of the Caragana stem with good mechanical properties for more than eight years was used, from Dingxiang City, Shanxi Province, China. The mechanical parameters are shown in Table 2 [2, 12]. For the rapid production of Caragana particles, this study divided the crushed Caragana into 6 grades using the sieve with different mesh: 0~0.16mm, 0.16~0.63mm, 0.63~1.25mm, 1.25~2mm, 2~4mm and 4~4.75mm. In this experiment, the quality reinforcement ratio of the Caragana pellet (the ratio of the quality of the Caragana and the quality of the dry soil) were 0, 0.1%, 0.15%, 0.2%, 0.25% and 0.3% respectively.

Due to the absence of coarse aggregate during the manufacture of the specimen, the size of the specimen is not limited by the size of the largest coarse aggregate. The corresponding specimen was made by the self-made mold. Compressive and shearing specimens with φ30mm×50mm are used; the length of the tensile specimen is 140mm, the length of transition section 20mm, the diameter of the end 40mm, and the diameter at the middle of the preset fracture 20mm. The bending specimen is 40mm×40mm×160mm; torsional specimens φ10mm×60mm. When the sample is made, the moisture content of the specimen is controlled at 15% and compacted to the density of 1.5 g·cm-3. To reduce the random error, 555 samples were processed, each process making 3 parallel samples, and average the results. The specimens were dried for 27 days under indoor conditions to ensure their full strength.

Table 1 Physical properties of soil samples

Plastic limit w_p/%	Plasticity index I_p/%	Optimum moisture content w_{opt}/%	Maximum dry density ρ_d/$g{\cdot}cm$-3	Percentage content of particle gradation /%					
				2~1	1~0.5	0.5~0.25	0.25~0.1	0.1~0.075	< 0.075
16.38	18.9	15.34	1.53	1.58	1.94	2.47	30.35	30.72	32.94

Table 2 Mechanical parameters of reinforced material

Type	Tensile strength /MPa	Elastic modulus /MPa	Elongation at break /%
Caragana fiber	300~900	12~45	8~12
Polypropylene	25~35	28~40	10-15

1.2 Test equipment and methods

The experiment was carried out at the biomechanics laboratory , engineering college, shanxi agricultural university, China. Throughout the process, the machines used for grinding are shredders (Yongkang Tianqi Shengshi Co., Ltd., TQ~1000Y, CHINA), drying is cement test kit (Luda Construction Instrument Co., Ltd., YH~40H, CHINA).

Test device is universal testing machine controlled by the microcomputer (sans Material Inspection Co., CMT6104, CHINA), as shown in figure 1. The displacement control is adopted in the experiment, and the loading speed is 0.5mm/min. The test load starts from 0 and gradually applies linear load until the component is destroyed.

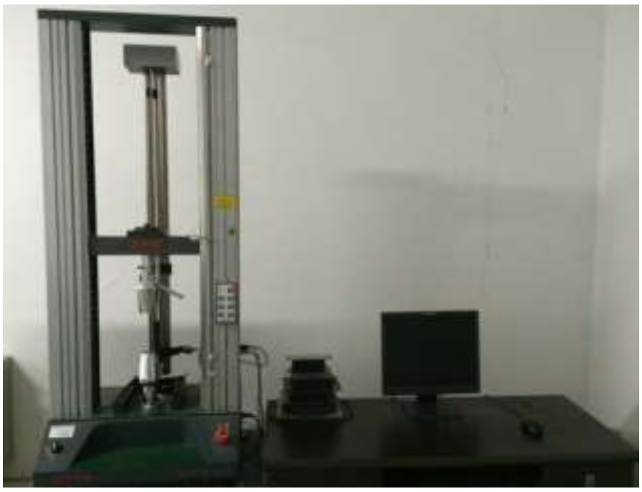

Fig. 1 Material testing machine controlled by computer

The compressive strength test adopts a flat cylinder indenter with a diameter of 10cm. double shear test. Shear strength tests were performed on double shear tests. The bending strength test method uses three point bending test to measure the bending strength of specimens, in which the specimen span is 150mm, and the ends of the bearing are left 5mm.Taking the influence of fixture deformation on the test results into account, the tensile strength test piece is fixed with 0.5mm 304 steel wire to ensure that it is not easy to slip. The lever arm of the torsion strength test fixture is a fixed value, L=50mm.

III. Results

Figure 4 shows the specimen's fracture in the basic form of tension, compression, bending, shear and torsion. When the content of Caragana is not higher than 15%, the brittle features of specimens are obvious. When the stress strain curve appears the first peak point, the first crack appears in the middle of the specimen. Then, as the load increases, the specimen is rapidly damaged. While the content of Caragana is higher than 15%, the same as the former, when the load reaches the yield strength, the surface of the specimen appears the first crack. With the increase of load, there are many fine cracks in the specimen. When the load continues to increase, a main crack appears in the cracks until it breaks. The specimen has bigger deflection and better ductility.

When the specimen is sheared, the crack process is not easy to be observed. It is easily concluded from the stress-strain curve that When the load is small, the stress-strain curve is approximately straight. With the increase of load, when the content of Caragana is low, the properties of brittle materials are obvious; when the content of Caragana increased, the properties of plastic materials is showed gradually, and with the increase of the content and length of Caragana, this phenomenon became more obvious.

Fig.4 Surface cracks of specimens (including bending, compressive, bending and tensile and torsional strength tests)

Excel software is used to calculate the mean value of repeated samples with limit values. The results are summarized as table 3:

Table3 Normal mechanical test results of strengthening material of Clay reinforced by Caragana

Reinforcement length of Caragana	Reinforcement ratio of Caragana /%	Experimental treatment	Ultimate tensile strength /KPa	Ultimate compressive strength /MPa	Ultimate bending strength /Mpa	Ultimate shear strength /MPa	Ultimate torsional strength /KN·m
0mm	0	T1	39.71	2.76	20.41	1.1	1.28
<0.16mm	0.05	T2	41.63	2.8	22	1.26	1.38
<0.16mm	0.1	T3	44.76	2.89	23.38	1.34	1.45
<0.16mm	0.15	T4	47.91	3	23.79	1.34	1.52
<0.16mm	0.2	T5	49.9	3.3	24.71	1.42	1.61
<0.16mm	0.25	T6	51.5	3.57	25.6	1.39	1.7
<0.16mm	0.3	T7	49.46	3.21	24.73	1.36	1.62
0.16~0.63mm	0.05	T8	47.07	2.9	26.03	1.39	1.54
0.16~0.63mm	0.1	T9	48.57	3.02	27.05	1.49	1.62
0.16~0.63mm	0.15	T10	50.25	3.12	27.62	1.63	1.77
0.16~0.63mm	0.2	T11	51.6	3.76	28.85	1.77	1.86
0.16~0.63mm	0.25	T12	53.37	3.68	29.42	1.5	1.93
0.16~0.63mm	0.3	T13	51.08	3.24	26.74	1.25	1.77
0.63~1.25mm	0.05	T14	49.49	3.59	27.99	1.41	1.71
0.63~1.25mm	0.1	T15	50.9	3.68	29.91	1.61	1.78
0.63~1.25mm	0.15	T16	52.94	3.8	31.88	1.78	1.83
0.63~1.25mm	0.2	T17	55.77	4.2	32.96	1.83	1.93
0.63~1.25mm	0.25	T18	57.33	4.5	31.02	1.7	2.03
0.63~1.25mm	0.3	T19	54.92	4.36	33.54	1.49	1.89
1.25~2mm	0.05	T20	53.49	3.94	36.39	1.61	1.73
1.25~2mm	0.1	T21	56.1	4.09	38.03	1.78	1.9
1.25~2mm	0.15	T22	57.02	4.2	39.25	1.89	66.63
1.25~2mm	0.2	T23	59.05	4.73	40.5	1.98	2.03
1.25~2mm	0.25	T24	60.84	4.81	41.52	1.75	2.15
1.25~2mm	0.3	T25	55.84	4.49	39.13	1.71	2.01
2~4mm	0.05	T26	57.65	4.45	41.52	1.74	1.83
2~4mm	0.1	T27	59.47	4.52	44.57	1.78	1.92
2~4mm	0.15	T28	62.08	4.6	45.7	1.72	2.02
2~4mm	0.2	T29	63.87	4.75	47.45	2.05	2.15
2~4mm	0.25	T30	65.79	4.9	49.05	1.89	2.23
2~4mm	0.3	T31	63.48	4.5	47.05	1.69	2.02
4~4.75mm	0.05	T32	63.56	5.01	46.73	1.87	2.03
4~4.75mm	0.1	T33	65.45	5.13	49.53	2.01	2.12
4~4.75mm	0.15	T34	67.41	5.26	52.49	2.11	2.24
4~4.75mm	0.2	T35	68.73	5.62	55.05	2.13	2.32
4~4.75mm	0.25	T36	71.77	5.59	57.55	2.19	2.44
4~4.75mm	0.3	T37	69.75	5.28	53.7	2.03	2.28

IV. .DISCUSSION

3.1 The mechanical properties variation trend with the quality reinforcement ratio and the length of the reinforcement

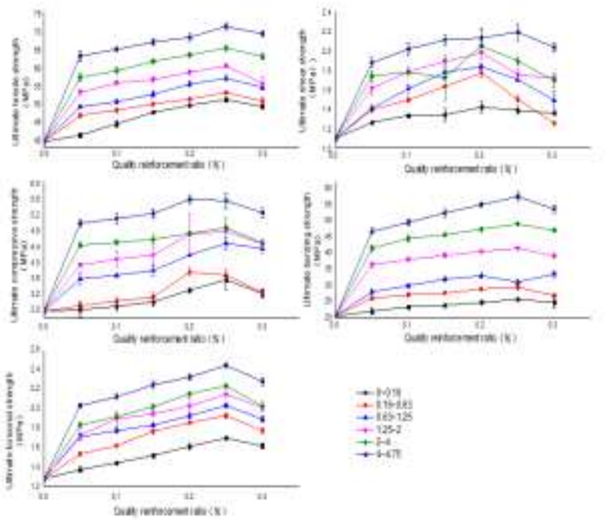

Fig. 5 The tendency of mechanical property with the increasing of the reinforcement ratio and length

Figure 5 is the stress-strain curve corresponding to the various basic mechanical indexes. It can be seen from the curve that under the different reinforcement length of caragana, the ultimate tensile strength, ultimate compressive strength, ultimate bending strength, ultimate shear strength and ultimate torsion strength all increase with the increase of quality reinforcement ratio. In addition to the ultimate shear strength reaches the maximum when the reinforcement ratio is 0.2%, the other basic mechanical indexes reach the maximum at 0.25%. When the reinforcement rate is 0.25%, the average ultimate tensile strength, ultimate compressive strength, ultimate bending strength and ultimate torsional strength of different reinforcement lengths were 39.71KPa，2.76MPa，20.41MPa 和 1.28KN·m respectively, as quality reinforcement ratio increased from 0% to 0.25%g/cm3, respectively, increasing by 51.36%, 51.36%, 63.55%, 62.59%. When the reinforcement continues to increases, strength begins to decrease. Caragana particles are randomly distributed in soil base, and form a spatial network connection system due to frictional force. When subjected to load, this system can bear part of the stress and delay the destruction of specimens [13]. When the quality reinforcement ratio is relatively less, the friction between Caragana and soil base is small, so the connection ability of spatial network is not obvious. When the quality reinforcement ratio exceeds the optimum value, with each gradient added, the porosity will increase a lot, the space network system will be destroyed, and the strength will be weakened.

3.2 Optimization of material ratio parameters for material Clay reinforced by Caragana

SAS software was used to analyze the factor effect of the data，the results shows that the determination coefficient of the factor effect model is very high, the significance P value is less than 0.01, so the analysis of variance is effective. The main factors affecting the effect successively are length of reinforcement, quality reinforcement ratio, Interaction between reinforcement length and quality reinforcement ratio. Except for the P value corresponding to the interaction of reinforced length and reinforced ratio of the ultimate torsional strength, the rest of the significant P values were less than 0.0001, indicating the effect of test factor to study the effect is extremely significant.

As shown in table 9, the ultimate tensile strength effects ranged from high to low in the mean value is T36, T37, T35 and T34, indicating that the higher ultimate tensile strength is the reinforcement length 4~4.75mm, the quality of Caragana 0.25%. The ultimate compressive strength effects ranged from high to low in the mean value is T35、T36、T37、T34, indicating that the higher ultimate compressive strength is the reinforcement length 4~4.75mm, the quality of Caragana 0.20%. The ultimate bending strength effects ranged from high to low in the mean value is T36、T35、T37、T34, indicating that the higher ultimate bending strength is the reinforcement length 4~4.75mm, the quality of Caragana 0.25%. The ultimate shear strength effects ranged from high to low in the mean value is T36、T35、T34、T29, indicating that the higher ultimate shear strength is the reinforcement length 4~4.75mm, the quality of Caragana 0.25%. The ultimate torsional strength effects ranged from high to low in the mean value is T36、T35、T37、T34, indicating that the higher ultimate torsional strength is the reinforcement length 4~4.75mm, the quality of Caragana 0.25%.

Table 9 Mean multiple comparisons of test processing (Duncan’s Multiple Range Test)

Response	Experimental treatment	Mean	Observation number	0.05 significance
Ultimate shear strength	T36	2.1867	3	A
	T35	2.1267	3	AB
	T34	2.1067	3	ABC
	T29	2.0467	3	BCD
Ultimate tensile strength	T36	71.767	3	A
	T37	69.75	3	B
	T35	68.733	3	B
	T34	67.41	3	C
ultimate compressive strength	T35	5.62	3	A
	T36	2.59	3	A
	T37	5.28	3	B
	T34	5.26	3	BC
Ultimate bending strength	T36	57.55	3	A
	T35	55.047	3	B
	T37	53.7	3	C
	T34	52.49	3	C
Ultimate torsional strength	T36	2.4433	3	A
	T35	2.3233	3	B
	T37	2.2767	3	BC
	T34	2.2433	3	C

To sum up, the best treatment for the ultimate compressive, tensile, bending, shear and torsional strengths is the T36, namely the optimum matching technology for the strengthening material Clay reinforced by Caragana is that Caragana reinforcement length 4~4.75mm, the quality of Caragana reinforcement rate 0.25%.

V. CONCLUSION

Through the unconfined compression test, tensile strength test, bending strength test, double shear test and torsional strength test, the basic mechanical properties of the strengthening material Clay reinforced by Caragana was studied.

1) The mechanical properties change tendency of the strengthening materials with the increase of the reinforcement ratio of the Caragana and the length of the reinforcement in the form of basic deformation such as stretching, compression, bending, shearing and torsion is analyzed. The results showed that the strength of the Clay reinforced by Caragana increased with the increase of the length of the reinforcement, and when the reinforcement ratio was between 0.2%~0.25%, strength reached the maximum.

2) Through data analysis, the length of Caragana and the reinforcement ratio of Caragana are determined as the two factors related to Caragana having an important influence on the strength of the material. Due the interface between Caragana and soil base, Caragana can bear part of the load, thus enhancing the strength of the soil.

3) Multivariate analysis of variance by SAS shows that the optimum matching technology for the strengthening material Clay by reinforced Caragana is that Caragana reinforcement length 4~4.75mm, the quality of Caragana reinforcement rate 0.25%.

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