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Research Article

Mechanical Performance and Durability Evaluation of Sandstone Concrete

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Enlarging local raw material utilization and reducing project costs is a new trend in the construction field. Under this background, sandstone was utilized in a cement-stabilized base in this study. The mineral composition of sandstone and the proportion of each mineral composition in the parent rock were analyzed using X-ray diffraction. To verify its feasibility, sandstone, syenite, marble, and basalt aggregates were selected to test the mechanical properties and road performance of the four aggregate concretes at 7, 28, 90, and 180 days. The test results showed that although the sandstone slump was the lowest at 60, the workability met the requirement. Compressive strength, tensile elasticity modulus, and axial tensile strength of concrete increased with age in all the concrete specimens, and the strength at each inspection time of sandstone was equivalent to that of marble, lower than that of basalt but higher than that of syenite. The early compressive strength of sandstone concrete is slightly lower than the compressive strength of marble concrete, and the 7 d and 28 d strengths were lower than 14% and 11%, respectively, but their 90 d and 180 d compressive strengths were the same. The crack resistance and frost resistance of sandstone were slightly inferior to those of syenite but better than those of basalt and marble. After 300 freeze-thaw cycles of the four aggregate concretes, the mass-loss rate of the test specimens was less than 5%, indicating that the frost resistance can meet the requirements. The various technical indexes of sandstone mixture could meet the current industry standards, and crack resistance, frost resistance, and fatigue resistance were good, which verified the feasibility of using sandstone for cement-stabilized base and provided a low-cost alternative for road construction.

1. Introduction

With the rapid development of logistics transportation, more and more highways need to be constructed and extended which made the road materials demand always increasing. Considering the lack of high-quality stone materials in some highway's construction areas of China, coupled with the high cost of procurement and transportation, the road engineering cost is more and more expensive. To shorten the transportation distance, save construction costs, and ensure the progress and quality of the project, the construction materials should be used as much as possible to fully develop and utilize the natural stones along the road. Although there are fewer amounts of limestone, basalt, diabase, and syenite available for highway construction in western China, it has a large amount of sandstone resources. Using sandstone as much as possible becomes a better choice for road construction. It can reduce transportation distance, and obtaining raw material in local also makes a better balance of filling and excavation during the construction process. Therefore, based on the current research in this field [1–7], the sandstone is systematically studied.

Ličev et al. [8] applied micro-CT and FOTOM systems to evaluate the internal structure of sandstone, measured the volume of pore space or other statistical values of sandstone samples, and found that changes in internal structure affected the strength characteristics of building stone. Grigoriev et al. [9] verified the numerical model of uniaxial compression tests of concrete and sandstone samples at different strain rates and fully described the behavior of brittle materials under dynamic loading. Zhang et al. [10] studied the deformation characteristics of different aggregate concretes through experiments, including the effects of different aggregates on the elastic modulus, ultimate tensile value, and dry shrinkage of mortar and concrete. Xie et al. [11] studied the damage behavior of argillaceous sandstone under the effect of dry and wet cycles. As the number of cycles increased, the mechanical parameters gradually decreased. Besides, Sengul et al. [12] found that when the compressive strength of the sandstone parent rock is greater than 60 MPa, C25~C40 concrete can be prepared that meets the requirements of workability, crack resistance, permeability resistance, and abrasion resistance. However, there are large differences among sandstones with different lithological characteristics. Danza et al. [13] compared granite, limestone, dolomite, and natural sandstone and concluded that the shape and structure of aggregates affect the mechanical properties of concrete. Kılıc et al. [14] studied the effects of five different aggregate types (gabbro, basalt, tetragonal, limestone, and sandstone) on the compressive strength, flexural tensile strength, and abrasion resistance of concrete. Gabbro concrete shows the highest compressive strength, flexural tensile strength and abrasion resistance, while sandstone shows the lowest compressive strength, flexural tensile strength, and abrasion resistance. It is concluded that the strength and texture of aggregate will affect the compressive strength, flexural tensile strength, and abrasion resistance of concrete. Qing and Longhui [15] systematically studied sandstone aggregates and their effects on the workability, mechanical properties, and durability of low-grade concrete. It was found that the working performance, mechanical properties, and durability of sandstone met the requirements of use. The above studies have verified the feasibility of using sandstone aggregate in low-grade concrete and provided basic data support for the application of sandstone in highway engineering.

From the literature above, it can be concluded that the application research of sandstone in road engineering is still infancy, and there is a lack of professional and systematic research on the basic properties and road performance of sandstone all over the world, particularly in crack resistance, frost resistance, and durability.

To achieve this objective, three aggregate types, syenite, marble, and basalt aggregates, were selected and compared with sandstone aggregates by mechanical properties according to the compressive strength test, tensile elasticity modulus test, and axial tensile strength test. Besides, concrete crack resistance, frost resistance, and fatigue resistance were tested to ensure the road performance of sandstone using the stabilized gravel stratum, and then local raw material utilization was enlarged and project costs were reduced.

2. Materials and Methods

2.1. Materials

2.1.1. Cement. The cement used for cement-stabilized macadam base is ordinary Portland cement (P•O42.5), and the physical and mechanical properties as well as the chemical composition of the cement (as determined by XRF analysis) are summarized in Table 1.

Table 1: Characteristics of Portland cement.

Parameter	Value
Physical characteristics	
Density (g/m^3)	3.10
Initial set (min)	175
Final set (min)	315
Mechanical characteristics	
3-day compressive strength (MPa)	16.9
7-day compressive strength (MPa)	25.0
28-day compressive strength (MPa)	42.0
Chemical characteristics	
SiO_2 (%)	21.67
Al_2O_3 (%)	4.76
Fe_2O_3 (%)	4.68
CaO (%)	61.31
MgO (%)	2.88
SO_3 (%)	1.98
Na_2O (%)	0.20
K_2O (%)	0.51
Equivalent alkali (%)	0.54
SiO_2 (%)	21.67
LOI (%)	4.84

2.1.2. Aggregates. Many types of sandstone have been used along the project. Sandstone should be used according to local conditions, and three other commonly used aggregates (syenite, marble, and basalt) are selected for comparison. Therefore, all sandstone types along the route are selected for testing. Lithology is a property that reflects the characteristics of rock, such as color, composition, structure, cement and cement type, and special minerals. According to different lithologies, it can be divided into silty mudstone, muddy siltstone, muddy fine sandstone, gravelly fine sandstone, and coarse sandstone. Random survey and sampling of sandstones along the northern Shaanxi area were carried out, and powder crystal X-ray diffraction tests were performed on different types of sandstones [16]. The results of mineral composition, basic physical indicators, and microstructure parameters are shown in Tables 2 and 3.

Through an in-depth investigation, it is found that the sandstone deposition and diagenesis time in northern Shaanxi is relatively short, resulting in low water-saturated compressive strength and poor mechanical engineering properties, as shown in Table 4. Table 5 shows the test results of sandstone technical indicators.

The physical properties of the coarse aggregates selected for this study are shown in Table 6. The Los Angeles abrasion index, water absorption ratio, porosity index, elongated particles, and crushing value of the aggregate rocks are presented in Table 7.

2.1.3. Fly Ash. The previous experimental research found that when the amount of fly ash is 3 to 5%, the strength of the mixture is most favorable. Excessive fly ash can easily form a mirror surface, so the recommended amount of fly ash is 4%. The chemical composition of fly ash is shown in Table 8.

Table 2: Mineral composition of sandstone.

Lithology	Rock number	Quartz	Feldspar	Calcite	Dolomite	Hematite	Montmorillonite	Chlorite	Illite	Kaolin	Clay minerals
Silty mudstone	Mudst	21	4	24	8	4	10	8	12	9	39
	Slst1	39	6	19	0	1	15	5	10	5	35
Muddy siltstone	Slst2	43	10	18	0	3	5	6	10	5	26
	Slst3	44	13	8	9	1	5	5	8	5	23
Muddy fine sandstone	Pltst	35	3	27	0	3	10	12	5	5	32
Gravelly fine sandstone	Gitst	30	11	25	2	3	10	7	8	4	29

Table 3: Basic physical indexes and microstructure parameters of sandstone.

Lithology	Rock number	Density, ρ (g·cm^{-3})		Coefficient of water saturation, wa (%)	Porosity, n (%)	Relative density, Gs	Bulk density, ρD (%)	Particle area ratio, GAR (%)	Particle contact rate, Gc (%)	Relative average particle size, φ	Standard deviation, σ
		Dry density, ρd	Saturation density, ρsat								
Silty mudstone	Mudst	2.38	2.54	6.72	11.19	2.68	8.20	4.50	0.4	—	—
	Slst1	2.53	2.61	1.74	5.95	2.69	16.20	14.00	4.0	4.83	0.55
Muddy siltstone	Slst2	2.66	2.67	0.53	2.56	2.73	87.15	65.46	52.1	4.32	0.51
	Slst3	2.62	2.66	1.20	3.32	2.71	35.40	36.50	24.0	4.38	0.78
Muddy fine sandstone	Fnst	2.34	2.47	5.52	12.62	2.67	26.70	16.00	10.2	3.42	0.48
Gravelly fine sandstone	Pltst	2.68	2.70	0.71	2.55	2.75	58.20	62.80	40.3	3.81	0.78
Grits	Gitst	2.20	2.29	4.74	17.3	2.66	14.30	—	3.0	2.52	0.91

Table 4: Water-saturated compressive strength of original rock (sandstone).

Number	Specimen size (mm)			Area (mm^2)	Failure load (kN)	Ultimate strength (MPa)	Average value (MPa)
	Length	Width	Height				
1	52.69	52.1	51.8	2744	240.2	87.5	66.1
2	49.9	50.5	19.2	2520	200.8	79.7	
3	49.7	49.9	50.1	2480	140.6	56.7	
4	50.5	50.1	49.9	2530	182.3	72.0	
5	50.1	52.1	50.5	2609	131.5	50.4	
6	49.1	50.2	50.1	2465	123.7	50.2	

Table 5: Sandstone technical index test results.

Item	Density	Water absorption (%)	Elongated particles (%)	Crushing value (%)
Actual measurements	2.661	4.31	10.2	25
Standard value	≥2.6		≤15	≤26

Table 6: Physical properties of sand.

Aggregate rock type	Fineness modulus	Apparent density (kg/m^3)	Powder content	Saturated-surface-dried moisture retention
Syenite	2.67	2690	16.6	2.1
Sandstone	2.78	2690	17.7	1.6
Marble	3.09	2730	13.2	1.2
Basalt	2.45	2820	18.9	2.4

Table 7: Aggregate technical index.

Aggregate rock type	Abrasion (%) (LA 500)	Water absorption (%)	Porosity (%)	Elongated particles (%)	Crushing value (%)
Syenite	16.20	0.42	2.31	7.3	31
Sandstone	96.18	4.31	10.10	10.2	25
Marble	24.14	1.34	1.13	3.3	18
Basalt	23.66	2.29	4.21	8.1	4

Table 8: The chemical composition of fly ash (%).

Sample	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	K_2O	Na_2O	SO_3	LOI
Fly ash	53.08	3.40	1.16	8.89	23.46	0.70	0.18	0.43	3.85

Table 9: Mix proportion of concrete (kg/m^3).

Aggregate type	Water	Cement	Fly ash	Sand	5~20 stone	20~40 stone	Water-reducing agent
Syenite	118	212	91	710	580	680	1.82
Sandstone	118	212	91	706	578	678	1.52
Marble	118	212	91	717	586	689	1.52
Basalt	118	212	91	744	608	713	1.82

2.2. Methods

Technical Route. Choose four kinds of aggregate concrete such that they have the same water-to-cement ratio and same sand percentage; i.e., the water-to-cement ratio is 0.39, and the sand percentage is 36%. To evaluate the performance of concrete, four different types of aggregate concrete with the same types of cement and fly ash were selected. The mix proportion of concrete is shown in Table 9.

Concrete slump is a criterion used to judge the concrete workability in actual construction [17]. Generally, the larger the slump, the greater the fluidity of the concrete mixture. If the slump is large, it will easily cause the segregation of concrete, and if it is too small, it will cause difficulty in construction. The workability results of testing concrete are shown in Table 10. Comparing the slump of four kinds of aggregate concrete, the slump of sandstone is lower than the other three. Because the sandstone aggregate has a better aggregate shape, the total specific surface area is smaller than that of syenite and basalt but larger than that of marble, and the amount of cement slurry required to be wrapped is large. And the sandstone itself has high water absorption, the slump is relatively small at the same water consumption, and the workability is poor. Table 10 shows that the slump workability of concrete produced with different aggregates was within the target workability. Only the sandstone concrete showed very low slump workability because the feldspar mineral in the sandstone was highly altered and changed to clay. The mixing water was absorbed by the altered feldspar and it decreased the slump of fresh concrete.

Table 10: Slump workability of concrete made of different aggregate types (mm).

Concrete	Syenite	Sandstone	Marble	Basalt
Slump	75	60	105	70

2.2.1. Mechanical Properties of Concrete. Cubic samples with a side of 150 mm and prismatic samples with the dimensions of $150 \times 150 \times 550$ mm were cast from the fresh concrete mixtures [18]. The compaction of the samples was obtained utilizing vibration. There was no difficulty observed while compacting and preparing sandstone concrete specimens. All the test specimens were demoulded in 1 day and then cured in water. Curing temperature was $20^\circ C \pm 2^\circ C$.

For each age, thirteen specimens were employed in the measurement of compressive strength, tensile elasticity modulus, and axial tensile strength for each type of concrete. The compressive strength and the flexural tensile strength of concrete types were measured at 7 days, 28 days, 90 days, and 6 months. The strength measurements were carried out using the ELE 3000 kN hydraulic press.

(1) Compressive Strength. The compressive strength of concrete prepared using the selected coarse aggregates was determined by loading the specimens in uniaxial compression according to ASTM C 39 at a constant loading rate of 3.3 kN/s using a servo-controlled hydraulic testing machine of 3000 kN capacity. The compressive strength was determined after 7, 14, 28, and 180 days of curing [19].

(2) Tensile Elasticity Modulus. The tensile elasticity modulus was determined according to ASTM C 469. The specimens were tested in uniaxial compression at a constant rate of loading of approximately 3.3 kN/s using a servo-controlled hydraulic testing machine. A portable data logger was used to record the load and strain readings [20]. Longitudinal strains were measured using a compressometer that was fixed parallel to the direction of the applied load. The compressometer was centered at midheight of the specimen, and the compressive deformation was measured using two LVDTs located at diametrically opposite locations on the surface of the specimen.

(3) Axial Tensile Strength. The axial tensile strength of concrete can be experimentally determined from [21]: (1) uniaxial tensile test, (2) split cylinder tests, and (3) beam tests in flexure. The first method of obtaining the axial tensile strength test is referred to as a direct test for determining the axial tensile strength, while the second and third methods are indirect tests. The indirect method of applying tension in the form of splitting was suggested by Fernando Cerneiro, a Brazilian engineer, and the test is often referred to as the Brazilian test, although it was also developed independently in Japan. In this study, the axial tensile strength of concrete specimens prepared with the selected coarse aggregates was determined according to ASTM C 496.

2.2.2. Evaluation of Concrete Crack Resistance. According to the results of measured concrete mechanical properties, the ratio of tension and compression and the ratio of tensile elasticity modulus and compression strength of the four types of aggregate concrete at different ages are calculated, and the crack resistance of the four aggregate concretes is comprehensively compared from the ratio of tension and compression and the ratio of tensile elasticity modulus and compression strength [22].

2.2.3. Frost Resistance of Sandstone Concrete. According to the extreme climatic conditions in northern Shaanxi, parameters such as the test temperature, the test specimen maintenance cycle, and the number of freeze-thaw cycles in the freeze-thaw test are determined to simulate the actual engineering environment of the grassroots level to the greatest extent [23]. Six freeze-thaw cycles were performed, and the mass-loss rate and relative dynamic elastic modulus retention of the test pieces were measured to evaluate the frost resistance of the concrete.

2.2.4. Fatigue Resistance of Sandstone Concrete. The split fatigue tests were performed on the MTS (material test system) [24]. The height of the test piece was measured with a vernier caliper before the test, and the loading speed of the splitting strength test was controlled to 1 mm/min. The relationship between load and vertical displacement was automatically recorded by the system. The loading stress of the split fatigue test was determined from the splitting strength test at 90 days and the corresponding stress ratio was selected to be 0.7. The load control mode is stress control, using a continuous 10 Hz sine wave, the test temperature is about 20°C, and the fatigue failure criterion is the failure of the test piece.

3. Results and Discussion

3.1. Influence of Aggregate Types on Concrete Strength

3.1.1. Effect of Aggregate Types on Compressive Strength of Concrete. The compressive strength test results of the four kinds of aggregate concrete at 7 d, 28 d, 90 d, and 180 d are shown in Figure 1. Figure 1 shows the variation of compressive strength with age for the concrete specimens prepared with the four types of aggregates selected for this study. As expected, the compressive strength increased with age in all the concrete specimens [25]. Furthermore, the data in Figure 1 indicate that the type of coarse aggregate had a significant effect on the compressive strength of concrete. The early compressive strength increased faster than the later compressive strength. The strength of syenite was the lowest, and the strength of basalt was the highest. The early compressive strength of sandstone concrete was slightly lower than the compressive strength of marble concrete, and the 7 d and 28 d strengths were lower than 14% and 11%, respectively, but their 90 d and 180 d compressive strengths were the same.

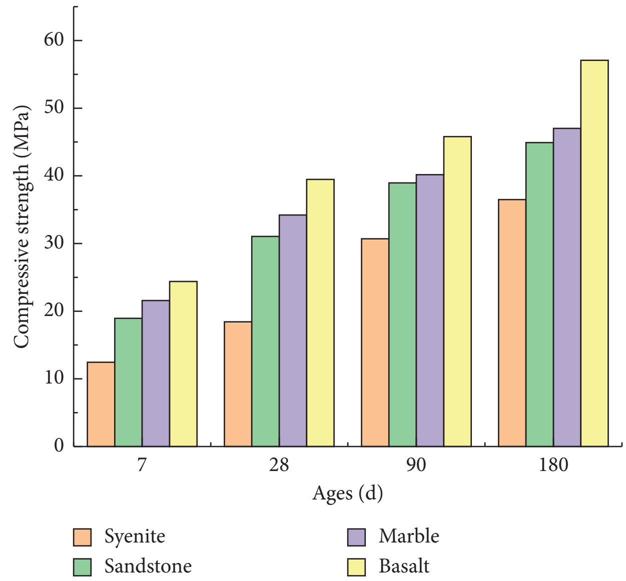

Figure 1: The results of four aggregates on compressive strength of concrete.

As for the difference in compressive strength of the four types of aggregate concrete, first of all, from the crushing value of aggregate, the crushing value of basalt was the lowest and that of syenite was the highest. Consistent with the smaller crushing value of aggregates, their compressive strength was greater because the compressive strength of sandstone, basalt, and marble aggregate concrete mainly depended on the strength of mortar and the strength of the interface between mortar and aggregate; although the crushing value of marble was lower than that of sandstone, the mortar strength of marble was higher than that of sandstone, so the compressive strength of marble concrete was slightly higher than that of sandstone concrete. The test results met the above phenomenon.

Besides, the effect of coarse grading on the compressive strength of concrete is significant because a good gradation has a larger bulk density and a smaller porosity. Among the four coarse aggregates, considering the effect of removing apparent density on the bulk density, the basalt aggregate had the largest bulk density and the syenite had the smallest bulk density, and the sandstone and marble had the bulk density in the middle range, which corresponded to the strength change of four kinds of aggregate concrete.

Sandstone grading is not as uniform as marble, and the water absorption of sandstone aggregate was higher than that of marble, resulting in sandstone's compressive strength being slightly lower than that of marble. The water absorption of the saturated surface of the syenite aggregate was the largest, and the effect of reducing the strength of the concrete was also the largest.

3.1.2. Effect of Aggregate Types on Tensile Elasticity Modulus of Concrete. The tensile elasticity modulus was determined after 14, 28, 90, and 180 days of curing. Figure 2 shows the tensile elasticity modulus of concrete specimens prepared with the four types of aggregates investigated in this study. The tensile elasticity modulus increased with age in all the concrete specimens. The tensile elasticity modulus of concrete was closely related to the strength of concrete. Generally, the tensile elasticity modulus of concrete increases as the compressive strength of the concrete increases. It could be seen from Figure 2 that the tensile elasticity modulus of the four aggregate concretes was consistent with the changing trend of the compressive strength of the concrete [26].

The shape and surface condition of the aggregate have a great influence on the tensile elasticity modulus of concrete. The granular gradation is reasonable and elongated, and flaky particles are few; the aggregate with a small crushing value has high tensile elasticity modulus. The syenite aggregate has a higher content of elongated and flaky particles, and because of its larger crushing value, its strength is not high and the particle gradation is poor, which results in syenite concrete with a low tensile elasticity modulus, and the 28 d tensile elasticity modulus was the same as the 90 d tensile elasticity modulus. The 180 d tensile elasticity modulus increased slightly.

Basalt concrete had the highest tensile elasticity modulus, which was related to its properties. The tensile elasticity modulus of basalt and marble increased with age. The difference in tensile elasticity modulus between marble and sandstone was relatively small, and the tensile elasticity modulus of marble was slightly higher than that of sandstone. For sandstone, the tensile elasticity modulus of concrete at 28 d increased less than that at 7 d, and it reached a peak at 90 d and stabilized.

3.1.3. Influence of Aggregate Types on Axial Tensile Strength of Concrete. It could be seen from Figure 3 that the change in axial tensile strength of the four types of aggregate concrete was not consistent with the compressive strength of the concrete [27]. Although they all increased with age, the axial tensile strengths of syenite and marble at 7 d, 28 d, 90 d, and 180 d were the same. At the age of 28 d, the axial tensile strength of sandstone was slightly lower than that of syenite and marble. The axial tensile strength at the other three days was higher than that of syenite and marble. The axial tensile strength of the basalt in the early stage was higher than that of the other three kinds of aggregates, but the axial tensile strength of the four kinds of aggregate concrete was not much different at 180 days.

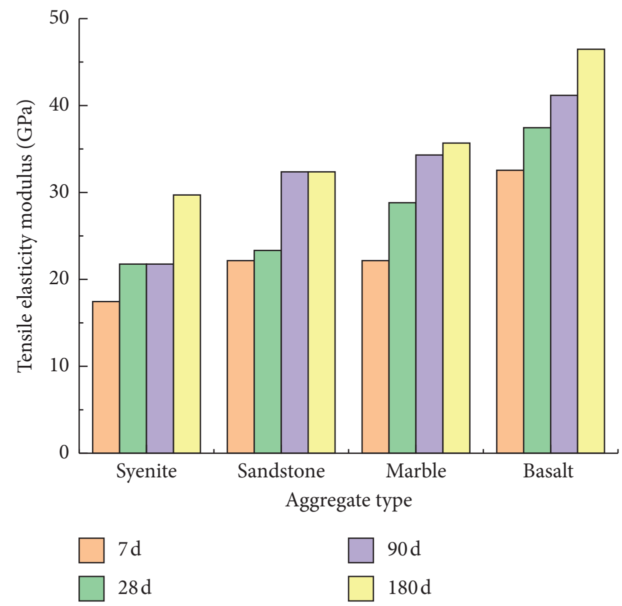

FIGURE 2: The tensile elasticity modulus of four types of aggregate concrete.

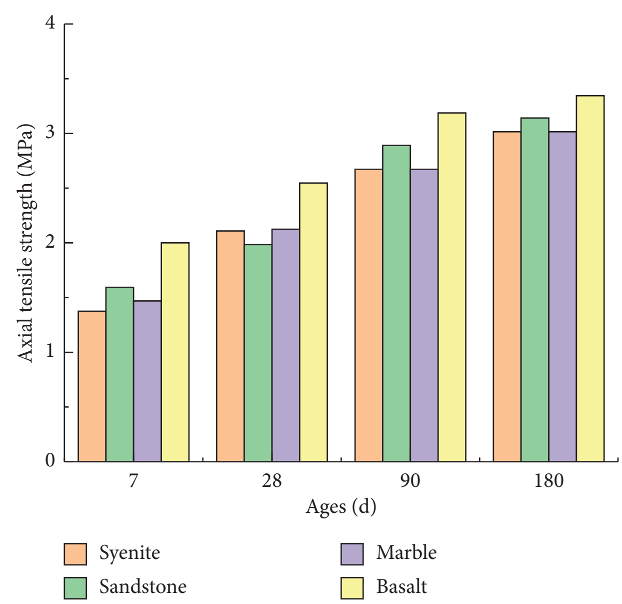

FIGURE 3: The axial tensile strength of four types of aggregate concrete.

3.2. Evaluation of Concrete Crack Resistance. Based on the results of Figures 1–3, the calculated ratio of tension and compression and the ratio of tensile elasticity modulus and compression strength of the four types of aggregate concrete at different ages are shown in Figures 4 and 5.

As can be seen from Figure 4, the ratios of tension and compression of the syenite aggregate concrete at 7 d, 28 d, 90 d, and 180 d were the largest, which were 0.11, 0.12, 0.09, and 0.08, respectively. Therefore, from the index of tension and compression ratio, it could be concluded that the crack resistance of syenite aggregate concrete was better than that of the other three types of aggregate concrete; the ratio of

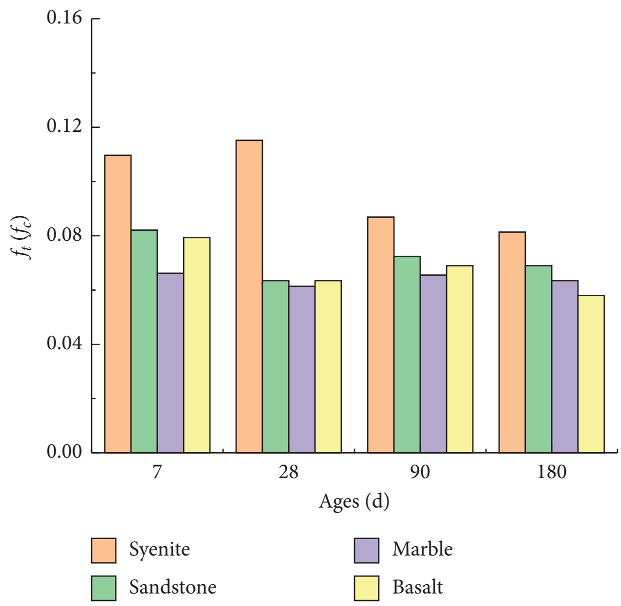

Figure 4: f_t/f_c of four types of aggregate concrete.

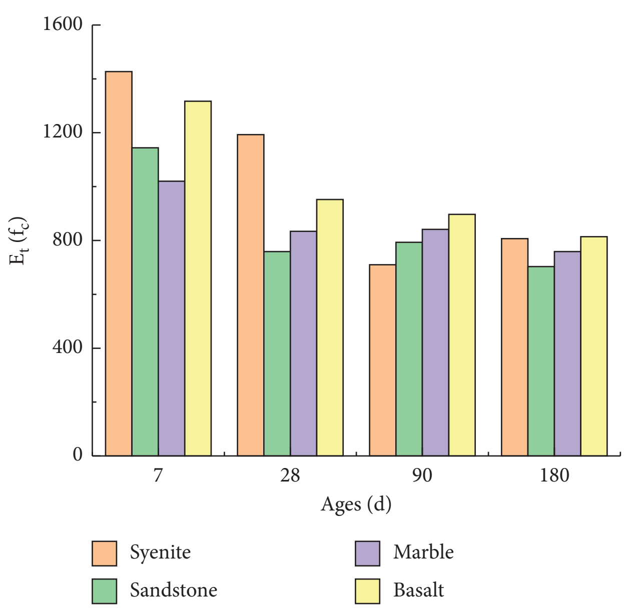

Figure 5: E_c/f_c of four types of aggregate concrete.

tension and compression of sandstone aggregate concrete was slightly higher than that of marble aggregate concrete, so the sandstone aggregate concrete had better crack resistance than the marble aggregate concrete [28]. The early tension-compression ratio of basalt aggregate concrete was close to that of sandstone aggregate concrete, while the minimum 180-day tension-compression ratio was 0.059.

From Figure 5, the crack resistance of the four kinds of aggregate concrete is compared using the ratio of tensile elasticity modulus and compression strength. Among the 7 d, 28 d, and 180 d ratios of tensile elasticity modulus and compression strength of the four aggregate concretes, the syenite concrete's ratio was relatively high, but the 90 d ratio of tensile elasticity modulus and compression strength was lower in the other three types of aggregate concrete at the same age; the 7 d, 28 d, 90 d, and 180 d ratios of tensile elasticity modulus and compression strength of sandstone and marble were lower than those of basalt. This is because the compressive strength at 7 d and 28 d of syenite concrete was much lower than that of the other three types of concrete.

Although the tensile elasticity modulus of basalt was greater than that of syenite, the ratio of tensile elasticity modulus and compression strength of syenite concrete at 7 d and 28 d was slightly higher than that of basalt concrete at the corresponding age. Therefore, by comprehensive comparison, the crack resistance of basalt aggregate concrete was inferior to that of syenite aggregate concrete.

Comprehensively, comparing the crack resistance of the four types of aggregate concrete from the above two aspects, the ratio of tension and compression and the ratio of tensile elasticity modulus and compression strength, syenite aggregate concrete had the best crack resistance, followed by sandstone aggregate and marble aggregate concrete. Basalt concrete had the worst crack resistance.

3.3. Frost Resistance of Sandstone Concrete. It can be seen from Figure 6 that the mass-loss rate of the four types of aggregate concrete had the same change trend. As the number of freeze-thaw cycles increased, the mass-loss rate of concrete increased accordingly. When the number of freeze-thaw cycles is less than 100, the mass change of the concrete test block was not obvious, which indicated that the surface of the concrete specimen was intact without degradation. With the increase in the number of freeze-thaw cycles, the mass-loss rate of each test piece had gradually increased. When the number of cycles was 150 to 200, the increased rate of the mass-loss rate was the largest, which indicated that the concrete test piece spalled a lot in this interval and the quality loss was large [29].

After 300 freeze-thaw cycles of the four aggregate concretes, the mass-loss rate of the test specimens was less than 5%, indicating that the frost resistance could meet the requirements. Among them, the mass loss of sandstone and syenite was small, and the increase rate of the loss rate was the smallest, which indicated that sandstone and syenite had the best frost resistance, followed by marble. The basalt had the largest mass loss and the worst frost resistance.

It could be seen from Figure 7 that the relative dynamic elastic modulus of the four types of aggregate concrete had the same change trend. As the number of freeze-thaw cycles increased, the relative dynamic elastic modulus gradually decreased. The relative dynamic elastic modulus of basalt decreases the fastest, followed by marble and sandstone. The relative dynamic elastic modulus of syenite decreases the slowest, indicating that syenite had the best frost resistance, followed by sandstone and marble, and the frost resistance of basalt was worst. However, the four kinds of aggregate concrete met the relative dynamic elastic modulus retention of more than 60%, indicating that all four kinds of concrete met the requirements.

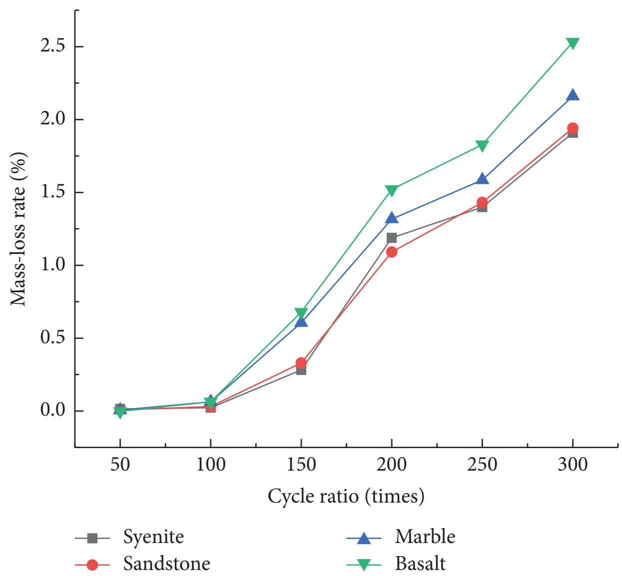

Figure 6: Mass-loss rate of concrete freeze-thaw cycles.

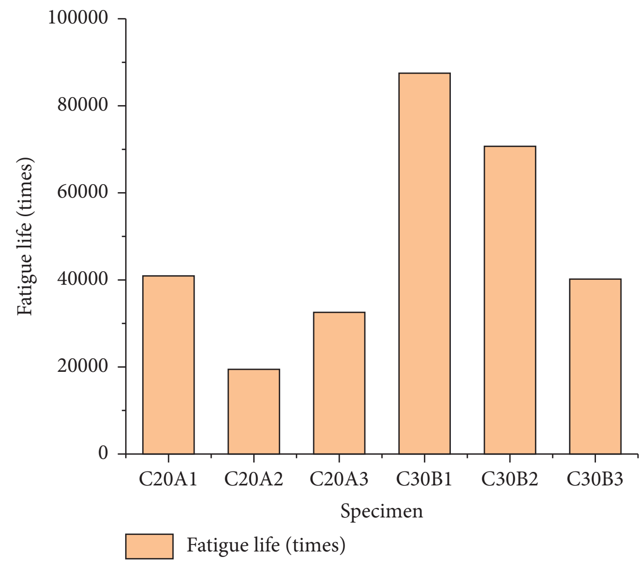

Figure 8: Fatigue test results.

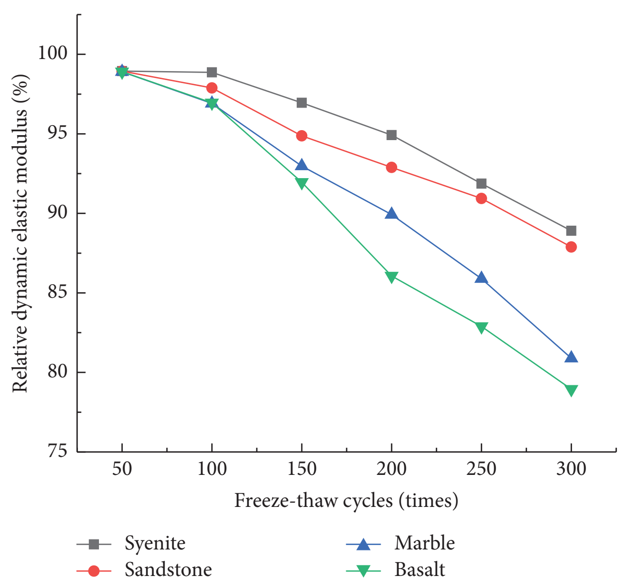

Figure 7: Relative dynamic elastic modulus of concrete during freeze-thaw cycles.

Considering the two methods which included evaluating frost resistance of mass-loss rate and relative dynamic elastic modulus, it was concluded that the four types of aggregate concrete met the requirements of frost resistance. Among them, syenite had the best frost resistance, followed by sandstone, marble, and basalt which showed relatively poor frost resistance.

3.4. Fatigue Resistance of Sandstone Concrete. The flexural tensile fatigue test of cement-stabilized macadam was also carried out using a material test system [30]. The load is a continuous half-sine wave load, the loading frequency is 10 Hz, the fatigue test is performed in a stress-controlled manner, and the fracture of the test piece is used as the material fatigue failure criterion. The test piece used the aforementioned 400 mm × 100 mm × 100 mm beam-type test piece. Three groups of C20 and C30 test pieces below 28 d age were subjected to a three-point loading fatigue test at a stress level of 0.7. Cement-stabilized macadam had a relatively large nominal maximum aggregate size, and it was inevitable that there was some nonuniformity during the forming process of the test piece, which resulted in a certain degree of dispersion in the fatigue test results. After excluding test points with relatively large dispersion, the test results are shown in Figure 8.

According to Figure 8, the fatigue life of C20 concrete was in the range of 20,000 times to 40,000 times, and the fatigue life of C30 concrete was in the range of 40,000 times to 90,000 times.

4. Conclusions

By studying mechanical performance and durability evaluation of sandstone concrete under different ages, the following conclusions could be drawn:

(1) Comparing the slump of four kinds of aggregate concrete, the slump of sandstone was lower than the other three, for the sandstone aggregate had a better aggregate shape, the total specific surface area was smaller than that of syenite and basalt but larger than that of marble, and the amount of cement slurry required to be wrapped was large, so the workability of sandstone was relatively poor but not prone to cause the segregation of concrete.

(2) According to strength test results, compressive strength and tensile elasticity modulus of sandstone concrete were lower than those of basalt concrete and marble concrete but higher than of syenite. Axial tensile strength of sandstone concrete was just lower

than that of basalt concrete and higher than that of the other two types of concrete.

(3) The four types of aggregate concrete met the requirements of crack resistance, frost resistance, and fatigue resistance, which showed that it is feasible to use the sandstone for cement-stabilized base and it reduces the cost of construction.

(4) The successful application of sandstone concrete on the Huangyan Expressway in northern Shaanxi provided data support for this study and played a positive role in future promotion and application.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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