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Study on Mechanical Properties of in Situ Granulated Recycled Cement Stabilized Macadam for Cement Concrete Pavement

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Abstract. The old cement concrete pavement has a good recycling value, compared with the ordinary recycling technology, in-situ granulation technology can quickly complete the deep crushing of old cement concrete pavement in place, which is fast and efficient, and has better economic benefits. In order to realize the recycling of the old cement concrete pavement, the properties of in-situ granulated recycled aggregate are researched in this study, factory recycled aggregate and natural aggregate through the method of crushing regeneration, and carried out mechanical properties test study on in-situ petrochemical recycled water-stabilized gravel. The results show that the in-situ granulated recycled aggregate of old concrete slab has good physical and mechanical properties and can be applied to cement stabilized macadam of asphalt pavement. The 7d unconfined compressive strength of recycled cement stabilized macadam can meet the strength requirements of asphalt pavement base and subbase.

Keywords. In situ granulation, recycled aggregate properties, reclaimed water stability, mechanical properties

1. Introduction

Coarse aggregate and fine aggregate are the main components of cement concrete, accounting for about 75% of the volume of concrete [1-2]. Due to the enhancement of environmental protection awareness in China, as well as the introduction of relevant policies and regulations, the mining of stone materials is becoming more and more difficult, so the recycling and secondary utilization of construction waste materials has become trend in the future. A large number of cement concrete pavements were built in rural China in the early stage. With the increase of service life, they are damaged to varying degrees. In order to meet the needs of development, "cement concrete pavement to asphalt concrete pavement" has become the main trend of rural highway development. Therefore, how to recycle the original cement concrete pavement has become a problem that must be solved [3]. The cement concrete pavement in situ broken into aggregates that meet the requirements of the graded aggregate, and a brand-new cement stabilized macadam base is formed by adding cement and water, in-situ mixing and rolling, which not only realizes the recycling of waste cement concrete

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panels, but also solves the problem of reflection cracks of the existing "cement concrete pavement to asphalt concrete pavement" [4-5].

2. Source and Performance Test of Aggregate

2.1. Source of Aggregate

In order to study the mechanical properties of in-situ granulated recycled cement stabilized macadam, three kinds of aggregates with different production processes were selected to compare the basic performance of the water stable mixture, which were the in-situ granulated gravel of cement concrete pavement, the crushed stone produced by jaw crusher in laboratory, and natural gravel. The three kinds of aggregates are classified according to the size of 4.75mm. Coarse aggregate is larger than 4.75mm and fine aggregate is less than 4.75mm.

2.2. Performance Evaluation of Coarse Aggregate

The physical property indexes of coarse aggregate mainly include: apparent density, water absorption, needle and flake, etc. the mechanical property indexes of coarse aggregate are generally expressed by crushing value. The coarse aggregate results are shown in table 1.

Table 1. Results of coarse aggregate.

Serial number	Items tested	Unit	Test results			Technical requirement
			In situ recycled aggregate	Plant recycled aggregate	Natural gravel	
1	Apparent density	(g/cm^3)	2.48	2.55	2.68	—
2	Water absorption	%	4.1	3.5	2.3	—
3	Content of needle flake	%	10.4	7.6	11.8	≤15
4	Content of soft rock	%	3.9	2.91	1.89	≤5
5	Crushing value	%	25.3	22.5	20.4	≤35

The experimental results show that:

(1) The content of needle flake, soft rock and crushing value of recycled coarse aggregate meet the technical requirements of relevant specifications.

(2) The crushing value and content of soft rock of recycled coarse aggregate are larger than that of natural aggregate, but the content of needle and flake is smaller, so it is impossible to judge the advantages and disadvantages of recycled aggregate and natural aggregate from the aggregate itself.

(3) It can be predicted that the mechanical properties of plant recycled aggregate are better than that of in-situ granulated aggregate.

2.3. Performance Evaluation of Fine Aggregate

The performance indexes of fine aggregate mainly include: < 0.075mm particle content, sand equivalent, liquid limit (below 0.6mm), plasticity index (below 0.075mm), etc. The performance test results of fine aggregate are shown in table 2.

Table 2. Results of fine aggregate performance.

Serial number	Items tested	Unit	Results			Technical requirement
			In situ recycled aggregate	Plant recycled aggregate	Natural gravel	
1	< 0.075mm particle content	%	12.7	6.5	7.8	≤20
2	Sand equivalent	%	62	57	70	≥50
3	Liquid limit (below 0.6mm)	%	19.0	19.3	16.2	≤28
4	Plasticity index (below 0.075mm)	-	6.0	5.8	4.3	≤9
5	Water absorption	%	9.0	6.6	3.5	—

The physical and mechanical properties of recycled fine aggregate were tested

(1) The particle content, sand equivalent, liquid limit (below 0.6mm) and plasticity index (below 0.075mm) of recycled fine aggregate meet the requirements of relevant specifications.

(2) The content of particles <0.075mm and sand equivalent of recycled fine aggregate are closer to the index required by the specification, which indicates that there is still a considerable amount of clay, dust and other impurities in recycled fine aggregate, which should be paid attention to during production and processing.

(3) Compared with the water absorption of coarse and fine aggregates, the increase of recycled aggregate is about 2 times, and that of natural aggregate is about 1.5 times. This is because the content of cement mortar in recycled fine aggregate is more than that in recycled coarse aggregate, and a considerable part of it exists in the form of cement mortar.

3. Mix Design

Referring to the design requirements of cement stabilized macadam base in technical code for highway asphalt pavement recycling (JTG f41-2008), the gradation range of cement stabilized macadam mixture is determined in table 3.

Table 3. Requirements for gradation range of cement stabilized macadam base.

Sieve aperture(mm)	37.5	31.5	26.5	19	9.5	4.75	2.36	1.18	0.6	0.075
Upper limit(%)	100	-	100	100	67	49	35	-	22	7
Lower limit(%)	90	-	66	54	47	29	17	-	8	0

According to the design experience, the cement dosage is 4.0%, 4.5%, 5.0%, 5.5%, 6.0% five proportions respectively. The optimum moisture content and the maximum dry density of specimens are determined by heavy compaction molding method. The results is shown in table 4.

Table 4. Results of cement stabilized macadam mixture.

Test method		In sit recycled cement stabilized macadam mixture	Plant recycled cement stabilized macadam mixture	Cement stabilized macadam mixture
The cement dosage is 4.0%	Optimum moisture content (%)	7.9	7.1	5.8
	Maximum dry density (g/cm^3)	1.981	2.019	2.296
The cement dosage is 4.5%	Optimum moisture content (%)	8.2	7.4	6.2
	Maximum dry density (g/cm^3)	2.004	2.030	2.305
The cement dosage is 5.0%	Optimum moisture content (%)	8.8	7.8	6.7
	Maximum dry density (g/cm^3)	2.011	2.038	2.310
The cement dosage is 5.5%	Optimum moisture content (%)	9.2	8.3	7.2
	Maximum dry density (g/cm^3)	2.027	2.049	2.321
The cement dosage is 6.0%	Optimum moisture content (%)	9.9	8.9	7.5
	Maximum dry density (g/cm^3)	2.037	2.055	2.328

7d age unconfined compressive strength index of pavement base of different grades in technical specification for highway asphalt pavement recycling (JTG f41-2008) is shown in table 5. Therefore, the 7-day immersion unconfined compressive strength design of recycled cement stabilized macadam with static pressure molding method is 3.5Mpa. The test results are shown in table 6.

Table 5. Technical requirements for cement stabilized recycled mixture.

Test items		Specified value of 7-day unconfined compressive strength(MPa)	
		Expressways and first class highways	Highway of class II and below
Unconfined compressive strength(MPa)	Base Not less than	3~5	2.5~3
	Subbase Not less than	1.5~2.5	1.5~2.0

Table 6. Test results of 7-day static pressure molding strength of cement stabilized macadam mixture.

Test items \ Cement Dosage(%)	4.0	4.5	5.0	5.5	6.0
Mean intensity value R_{avg} (MPa)	3.4	3.5	3.9	4.3	4.6
Coefficient of variation C_V(%)	4.98	5.41	3.42	4.33	7.87
Strength representative value $R_{rep}=R_{avg}(1-ZaCv)$	3.1	3.2	3.7	4.0	4.1

The optimal cement content is 5.0% in table 6. When the road mixing method is adopted according to the relevant specifications, it should be increased by 1.0%. Therefore, 6.0% is selected as the cement content for construction, and the optimal water content is 9.9%.

4. Comparative Study on Mechanical Properties of Reclaimed Water for In Situ Granulation

The premise of the application of in-situ granulated Petrochemical reclaimed water stability is that its bearing capacity must meet the requirements of road use and specifications. Therefore, it is necessary to compare and study the unconfined compressive strength, splitting strength and compressive modulus of resilience of recycled water stability with various gradations.

4.1. Unconfined Compressive Strength Test

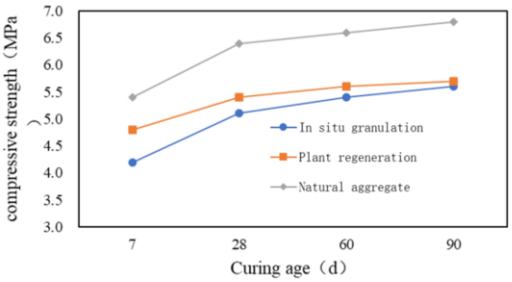

Figure 1. Unconfined compressive strength of 6% cement.

It can be seen from the test results in figure 1 that the 7d unconfined compressive strength of the three kinds can meet the minimum strength requirements of the base course in the technical specification for highway asphalt pavement recycling. The unconfined compressive strength of recycled water stabilized macadam is lower than that of water stabilized macadam formed by natural aggregate, and the strength of reclaimed water stabilized macadam in plant is higher than that of in-situ granulated water stabilized macadam.

4.2. Unconfined Compressive Modulus of Resilience Test

There are two methods to determine the compressive modulus of resilience, namely, t0808-1994 top surface method and t0807-1994 bearing plate method. The latter is only suitable for stabilizing fine-grained soil with inorganic binder, so the former is adopted in the test. The compressive modulus of resilience of the three mixtures were measured respectively shown in figure 2.

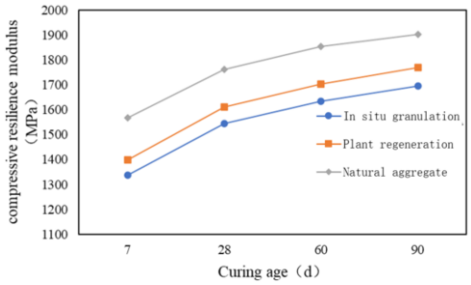

Figure 2. Growth chart of compressive resilience modulus of 6% cement.

The compressive resilient modulus of recycled water stabilized macadam is less than that formed by natural aggregate, and the strength of recycled water stabilized macadam in plant is higher than that of in-situ granulated water stabilized macadam, showing a consistent trend with unconfined compressive strength. The reason may be that in the compaction test, the dry density of recycled water stable material is small, which leads to the lack of final strength of water stable macadam. However, the uniformity of plant recycled aggregate is better, and the strength variation coefficient of shaped water stable macadam is smaller, so the performance of recycled water Stable Crushed Stone in plant is better than that of in-situ granulated gravel.

4.3. Splitting Strength Test

The splitting test is also called indirect tensile test. The pressure is applied to the specimen along the two sides of the diameter to make the cross section of the diameter subject to tensile stress. The tensile strength measured in turn is the indirect tensile strength of the specimen. As shown in figure 3.

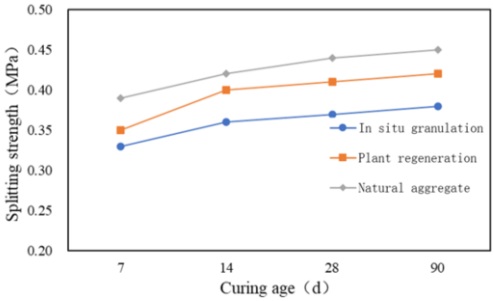

Figure 3. Growth chart of splitting strength of 6% cement.

Compared with unconfined compressive strength and compressive resilience modulus, the strength of natural aggregate water stable macadam is not significantly improved compared with recycled aggregate in the splitting strength test, and the splitting strength is greatly affected by the angularity of the aggregate and the impaction effect, while the recycled aggregate has rough surface, clear edges and strong embedding effect, which makes up for the shortage of the material itself to a certain extent.

5. Conclusion

In this paper, the mechanical properties of recycled cement stabilized macadam crushed from cement concrete pavement in situ are studied. The results show that the physical and mechanical properties of in-situ granulated recycled aggregate of old concrete slab are good and can be applied to cement stabilized macadam of asphalt pavement. The 7d unconfined compressive strength of recycled cement stabilized macadam can meet the strength requirements of asphalt pavement base and subbase. The research results of this paper not only realize the 100% recycling of waste building materials, but also solve the problem of reflection cracks from cement concrete pavement to asphalt concrete pavement, which is conducive to the sustainable development of highway, has broad application prospects, and meets the requirements of building a resource-saving and environment-friendly society in China.

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