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Strength assessment and mechanism analysis of cement stabilized reclaimed lime-fly ash macadam

Yu Sun *, Lihan Li

Key Laboratory of Road and Traffic Engineering of Ministry of Education, Tongji University, Shanghai, China

HIGHLIGHTS

- The higher substitution rate of RLFM is, the lower the strength of the mixture is.
- The higher mortar content is, the lower adhesion is, leading to lower strength.
- The attenuation amplitude of strength of CSR mixture is greater after freeze-thaw cycles.
- The attenuation amplitude increases as substitution rate increases, which is more sensitive to lower cement content.
- The hydration products are not bonded with aggregates directly, leading to the lower strength of CSR mixture.

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ABSTRACT

An experimental study was conducted to investigate the strength and influence factors of cement stabilized reclaimed lime-fly ash macadam (abbreviation CSR), compared with cement stabilized macadam (CSM). The results indicate that, substitution rate of reclaimed lime-fly ash macadam (abbreviation RLFM) remarkably affects the strength. Nevertheless, the effects of substitution rate actually depend on the mortar content to a great extent. From the microscale point of view, the hydration products of CSR mixture appear in the morphology of whisker, plush and loose structures, which are not bonded with aggregates directly, resulting in the lower strength of CSR mixture. The present work will be useful for the waste managers and policy makers particularly in developing nations where proper guidelines are still lacking.

1. Introduction

Semi-rigid base has become the main type of highway base and subbase owing to its higher strength, better rigidity, more excellent wholeness and water stability. At present, semi-rigid base includes cement stabilized aggregate, lime-fly ash stabilized aggregate, cement-fly ash stabilized aggregate and lime stabilized aggregate. Among them, cement stabilized and lime-fly ash stabilized aggregates are the most widely used [1–3]. In recent years, with the rapid growth of traffic, problems of structural destruction and road maintenance gradually occur, resulting in plenty of waste lime-fly ash macadam. Those used to be simply abandoned to landfill, which both wastes resources and pollutes environment. Therefore, regeneration and utilization of waste base materials has become an important research direction.

Actually, regeneration of the construction waste and reclaimed pavement materials used in road base has been researched, forming a set of relatively complete recycling technology, including digging, milling, crushing, and mixing [4–6]. Early in mid 1940s, reclaimed base materials has been researched to be applied to ordinary pavement reconstruction in the United States. Till 1990s, several countries such as America, Germany, France, and Finland have developed specialized recycling base machinery, making regeneration technique widely used in road maintenance [7]. For instance, the cement-stabilized blends with crushed brick as a supplementary material with up to 50% brick content and 3% cement were found to have physical and strength properties, which would comply with road authority requirements [8]. It has been reported that concrete made with recycled coarse aggregates has similar properties to that produced from natural aggregates [9]. And the research has provided results of the evaluation of

Abbreviations: CSR, cement stabilized reclaimed lime-fly ash macadam; RLFM, reclaimed lime-fly ash macadam.

* Corresponding author.
E-mail address: sunyu_tongji@qq.com (Y. Sun).

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RAP waste stabilized using reconstituted CKD and RHA wastes as highway construction material, as based on California bearing ratio determination [10]. Furthermore, cement-treated construction and demolition materials are researched to be viable construction materials for pavement base/subbase applications [11–13]. On the other hand, no significant difference is observed in the compressive strength of various concrete mixes prepared by natural and recycled aggregates, but only the tensile strength of the mix prepared with 25% recycled fine aggregates is comparable to that of the control concrete [14].

But different from natural aggregates, reclaimed lime-fly ash macadam (abbreviation RLFM) mainly consists of stones, mortar binder, stones attached by mortar and a small amount of stone chips. RLFM is characterized by its large diameter, rough surface, particle angularity and high porosity. Research shows that RLFM has high crushing value, high abrasion value, small bulk density, large moisture absorption, and more fine aggregates after milling due to the effect of lime-fly ash, which differs in the mechanical properties of natural aggregates [15–17].

In general, the research on regeneration technique of RLFM is in its initial stage, and the hitherto unknown properties of the materials requires further fundamental understanding in order to utilize these waste materials in pavement applications [18]. There still exist the problems of lacking regeneration design method, low strength of RLFM mixture, uncertainty of the performance and so on. In this study, especially for cement stabilized reclaimed lime-fly ash macadam (abbreviation CSR), unconfined compressive strength, indirect tensile strength, flexural tensile strength and frost resistance of CSR mixture are tested and analyzed compared with cement stabilized macadam (CSM) mixture. The research results will be helpful to improve the recycling technology of reclaimed base materials and provide reference for the design and performance evaluation of CSR mixture.

2. Materials and methods

2.1. Materials

2.1.1. Cement

The cement used is 32.5# composite silicate cement (P.C 32.5), and the parameters are shown in Table 1. The tests refer to "Test Methods of Cement and Concrete for Highway Engineering" (JTG E30-2005).

2.1.2. Natural aggregates

The natural aggregates used in the mixture are natural limestone, and the parameters and gradation are summarized in Table 2 and Fig. 1. The tests refer to "Test Methods of Aggregate for Highway Engineering" (JTG E42-2005).

2.1.3. Reclaimed lime-fly ash macadam

RLFM is provided by the waste of road base in Shanghai, China. With the impact crusher for crushing the original reclaimed material, the maximum size is controlled in 31.5 mm through adjusting the space between the hammer and the plate of the machine. Its properties and gradation are summarized in Tables 3 and 4. The tests refer to "Test Methods of Aggregate for Highway Engineering" (JTG E42-2005).

2.2. Experimental programme

2.2.1. Gradation design

Firstly, natural limestone is used in the CSM, which is the control mixture (named NA). Then, the whole aggregates (0–31.5 mm), coarse aggregates (4.75–31.5 mm), and fine aggregates (0–4.75 mm) in the CSM mixture are respectively replaced with RLFM, named RA, RCA, and RFA.

According to the gradation composition of limestone and reclaimed aggregates, the proportion of the mixes is summarized in Table 5 and gradation curve is shown in Fig. 2.

Through the compaction tests, dry density and moisture content of the mixes are summarized in Fig. 3 when the cement content is 4.5%. According to the test results, the maximum dry density and the optimum moisture content of the mixes can be calculated by quadratic polynomial fit method, which is listed in Table 6.

Seen from Table 6, compared with CSM mixture (NA), the optimum moisture content of CSR mixture (RA, RFA and RCA) increases significantly, and the maximum dry density decreases. Among them, the optimum moisture content of RA mixture is about as 3.5 times as that of NA mixture, while the maximum dry density is only about 0.6 times. In order to analyze the effects of cement content next, optimum moisture content and maximum dry density with different cement contents is calculated using the same test method above, and the results are shown in Table 7.

2.2.2. Unconfined compressive strength and indirect tensile strength

The mixtures prepared for the tests consist of 4 groups which are NA, RA, RFA, and RCA. According to "Test Methods of Materials Stabilized with Inorganic Binders for Highway Engineering" (JTG E51-2009), the mixtures are formed into standard specimens of Φ100 mm × 100 mm, and then cured for the age of 7 d, 28 d, and 90 d under standard conditions. Unconfined compressive strength and splitting strength of the mixtures are tested considering the influence of substitution rate, cement content, curing period and compaction degree.

2.2.3. Flexural tensile strength

The mixtures used in the test also consist of 4 groups which are NA, RA, RFA, and RCA, and the cement content of each group is 3.0%, 4.5% and 6.0%, respectively. The mixtures are formed into beam specimens of 10 cm × 10 cm × 40 cm using static pressure method, and then cured for 90d under the standard curing condition. Flexural tensile strength is tested at a loading speed of 50 mm/min.

2.2.4. Frost resistance

The mixtures used in the test also consist of 4 groups which are NA, RA, RFA, and RCA, and the cement content of each group is 3.0%, 4.5% and 6.0%, respectively. The mixtures are formed into standard specimens of Φ150 mm × 150 mm, and then cured for 28 d under the standard curing condition. Next, 5 times freeze-thaw cycles were planned to be carried out. For 1 freeze-thaw cycle, the specimens were frozen at the temperature of −18 °C for 16 h in the cryogenic box after curing, and then promptly thawed at the temperature of 20 °C for 8 h in the water channel. After that 1 freeze-thaw cycle was over and the second one could be conducted, but once the average loss rate of the specimen exceeded 5%, the process was terminated immediately.

Table 1
Physical indexes of the cement.

Fineness (%)	Loss on ignition (%)	Initial setting time (h)	Final setting time (h)	Compressive strength of 28 d (MPa)
4.4	5	5	20	35