Construction and Building Materials 161 (2018) 165–174

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

The effect of cement and reclaimed asphalt pavement on the mechanical properties of stabilized base via full-depth reclamation

Ali Reza Ghanizadeh [a,*], Morteza Rahrovan [b], Kazem Barkhordari Bafghi [b]

[a] Department of Civil Engineering, Sirjan University of Technology, Sirjan, Iran
[b] Department of Civil Engineering, University of Yazd, Yazd, Iran

HIGHLIGHTS

- Base and Subbase materials were blended with different percentage of RAP and stabilized with Portland cement.
- Compaction parameters, UCS and elastic modulus were determined for different stabilized RAP-soil mixtures.
- There is an exponential relation between UCS and cement percentage at a fixed ratio of RAP to soil.
- There is an exponential relation between elastic modulus and cement percentage at a fixed ratio of RAP to soil.
- UCS and elastic modulus of mixture increase by increasing cement or decreasing RAP content.

ARTICLE INFO

Article history:
Received 21 January 2017
Received in revised form 3 October 2017
Accepted 21 November 2017

Keywords:
Full-depth reclamation
Cement
Reclaimed asphalt pavement
Stabilization
Unconfined compressive strength
Elastic modulus

ABSTRACT

One method for improvement of distressed pavements is full-depth reclamation (FDR). In this technology, the present asphalt layer is pulverized and mixed with the aggregate layer beneath it and then the mixture is stabilized using a stabilizer agents such as Portland cement in order to increase the strength parameters of the mixture. The aim of this study is to evaluate the laboratory results of stabilizing the blend of reclaimed asphalt pavement (RAP) and aggregates with cement in order to be used as a treated base coarse in full-depth reclamation (FDR) method. The present study was conducted using two different types of aggregate soils. Compaction and unconfined compressive strength (UCS) tests were carried out on different ratios of RAP to aggregates of 0/100, 20/80, 40/60, and 60/40. Four cement contents of 3, 4, 5, and 6 percent were added and the samples were cured for 7 and 28 days after compaction. Results show that by assuming a constant percentage of RAP, by increasing one percent of the Portland cement, the UCS value for the stabilized layer including SP-SC and GW-GC increased by an average of 376 and 410 kPa, respectively. According to this research, the elastic modulus of FDR layers can be assumed between 9000 and 40,000 kPa with respect to soil type and dosage of RAP in FDR layers. Results also show that the optimum content of Portland cement for construction of FDR layers is between 3 and 4% for SP-SC soil and between 3 and 5% for GW-GC, respectively.

1. Introduction

Various methods of pavements recycling are used at present as cost-effective ways to improve flexible pavements. Generally, there are three methods of pavement recycling, including cold recycling, hot recycling, and full-depth reclamation [1].

If the damage to the pavement is related to the upper layers and the pavement has good conditions in respect of bearing capacity, hot recycling is a good alternative. If the pavement has structural weaknesses with serious damages, full-depth reclamation is suggested, and if the case lies between these two states, cold recycling can be effective [2]. It is important to determine whether pavement damage is structural or not. The main damage, indicating structural weakness of pavements, includes fatigue in wheels path, rutting, and reflecting cracking [3].

In full-depth reclamation, all the asphalt thickness, together with parts of the aggregates beneath it, is used to create a stabilized base course [4]. Application of full-depth reclamation results in an increase in a pavement's bearing capacity, structural strength and stability, extending of lifetime, and improvement of pavement conditions. In cases where the pavement structure has low bearing capacity, full-depth reclamation is very effective [2]. The costs of

* Corresponding author at: Department of Civil Engineering, Sirjan University of Technology, Sirjan 78137-33385, Iran.
E-mail address: Ghanizadeh@sirjantech.ac.ir (A.R. Ghanizadeh).

https://doi.org/10.1016/j.conbuildmat.2017.11.124
0950-0618/

full-depth reclamation are 25–50 percent lower than normal pavement reconstruction [5–7] Full-depth reclamation and cold recycling are more economic compared to other in-place recycling methods; however, full-depth reclamation is considered more desirable because it is able to remove structural problems as well [8,9]. Full-depth reclamation has been successfully employed by various departments such Maine [10]; Louisiana [11]; Kansas [12]; New Zealand [13]; Wisconsin [14]; Nevada [15,16]; Utah [6]; Saskatchewan [17]; Texas [18]; and Georgia [19] and has been reported to have the some advantages such solving pavement problems deeply and eliminating structural problems of the pavement; In this method, asphalt concrete layer and the layer beneath it are re-used and there is no need for material depots; Environmentally friendly and keeping the thickness of the pavement constant and preventing the increase in the thickness of the repaired pavement.

Full Depth Reclamation consists of five main steps including pulverization, blending the materials, formation, compaction and application of the surface course [10].

The depth of full-depth reclamation depends on the thickness of the present pavement, characteristics of the soil, and the number of traffic repetitions; however, it is normally selected 10–30 cm [1,20].

Due to the low strength of the RAP-aggregates blend, three different additives including mechanical treatment additives (e.g. virgin aggregates), chemical additives (e.g. Portland cement, hydrated lime, calcium chloride, and fly ash) and bitumen additives (e.g. bitumen emulsions) can be used to increase the strength of FDR layer [20].

The choice of additive depends on cost, availability, and effectiveness [21]. Generally, in FDR, cement is used in the case of coarse aggregates, while lime is used for fine aggregates like silt and clay [22]. Numerous researchers have studied the effects of various stabilizers on the cohesion of the particles and curing time in FDR. They have also examined various curing methods and have stated that curing is an important parameter in FDR [6,10,23–30]. Mixtures prepared via FDR require different curing times under different weather conditions in order to achieve the desired strength [31,32]. The main privilege of FDR is reusing the reclaimed asphalt pavement (RAP) and aggregates. The use of RAP in pavement layers, especially the base course, results in decreased waste and provision of useful materials for maintenance, rehabilitation, and reconstruction in road construction [6,33–36].

Treating the mixture of RAP and soil with an appropriate stabilizer results in increased strength and stiffness and allows its use in the base course [37]. Results of previous studies reveal that by increasing RAP and decreasing Portland cement in the mixture, optimum moisture content and maximum dry density of the treated material will be decreased [6,38–40]. Furthermore, increasing the proportion of cement in the mixture of RAP and aggregates increases UCS [6,24,38,39,41,42].

Taha et al. investigated the effect of cement and RAP on the unconfined compressive strength of the mixture of RAP and soil stabilized with cement. Their findings showed that increasing the content of cement or decreasing the proportion of RAP in the mixture increased optimum moisture content, maximum dry density, and unconfined compressive strength. Also, in the case that the blend of RAP and soil is effectively stabilized with cement, it can be used as the pavement course [34].

Yuan et al. conducted a study on the mixture of RAP and soil stabilized with Portland cement and found a linear relationship between the percentage of cement and unconfined compressive strength. They stated that increasing the percentage of cement increases unconfined compressive strength [36].

Yang and Wu showed a significant relationship between unconfined compressive strength and the percentage of cement and RAP. By increasing the amount of RAP, unconfined compressive strength is slightly increased at first but, then, it decreases. They also stated that in case of using higher percentages of cement (1.5, 2 and 2.5 percent), unconfined compressive strength decreases when the amount of RAP is increased [43].

Euch Khay et al. conducted a laboratory study on mechanical characterization of cement-treated soil-RAP blend. In their work, they kept the proportion of cement constant while varying the percentage of RAP. Their findings showed that increasing the percentage of RAP decreases unconfined compressive strength [44].

Full-depth reclamation (FDR) technology has been implemented in the city of Sirjan (Kerman province, Iran) since 2014 in order to improve distressed streets in this city. In this method, Wirtgen recycler (WR2500) moves on the pavement, pulverizing it together with the asphalt layer and aggregates beneath it. The machine then passes over the pulverized layer again and mixes the previously pulverized material with water and stabilizer. Due to improper design and construction of pavements in Sirjan streets, only one layer has been constructed under the asphalt concrete layer. The specifications of this layer is very close to aggregate base in some streets while in others is very close to aggregate subbase. Also, the underlying layer does not pass all specifications to be considered as aggregate base or subbase. This could be due to moving fine aggregate materials from subgrade soil toward the top layer over time and this has reduced sand equivalent value of top layer.

The present study is aimed at investigating the effect of various percentages of cement and reclaimed asphalt pavement on optimum moisture content, maximum dry density, unconfined compressive strength (UCS) of the treated base course in FDR. Furthermore, the elastic modulus of the cured samples was studied. Another goal of this research is suggestion of optimum percentage of Portland cement regarding to recycling depth (ratio of RAP to aggregate). Unlike previous researches, this study covers two different soil types and therefore makes it possible to compare the results. Also, in previous research, the aggregate materials have been standard aggregate base which passes all requirements. No additional percentage of fine aggregate or low sand equivalency has been reported for this material in previous researches.

2. Materials and methods

2.1. Aggregates

Two different types of soil were considered in this study, to be mixed with RAP. The first soil sample was taken from the existing aggregate course beneath the HMA layer of a street in Sirjan and the second soil sample was taken from the aggregate base material depot in Sirjan city. Fig. 1 presents the grain size distribution curve of the two soil samples. In terms of gradation, the first sample was close to grading

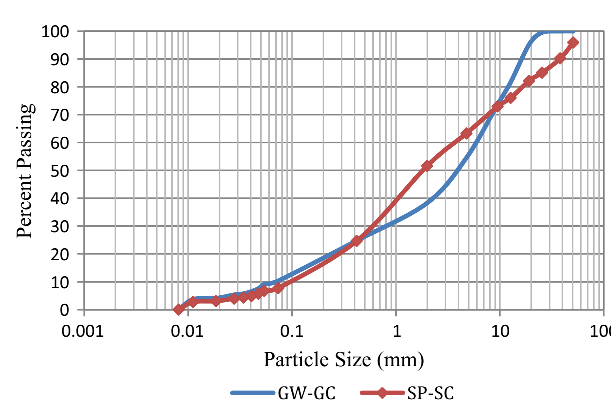

Fig. 1. Particle size distribution for two different types of soil.