PREDICTION OF UNCONFINED COMPRESSIVE STRENGTH OF OLD ASPHALT CONCRETE USING MULTIPLE REGRESSION

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ABSTRACT

The recycle of old asphaltic concrete material (OAC) with cement additive is a relatively new pavement improvement method in road geotechnical engineering in Thailand. This paper describes the test results of recycled old asphaltic concrete mixed with various amounts of cement additive (OACC) at different durations of curing time, compared to the OAC without any additive. The test results show that the strength of OACC increases with the increase in amount of cement additive. A multiple regression model was developed for predicting the unconfined compressive strength (UCS) of the recycled old asphaltic concrete with cement additive (OACC) using cement content and curing time as input. The performance evaluations showed that predictions by the multiple regression model are very satisfactory in estimating the UCS.

Keywords: multiple regression, pavement recycling, cement stabilization, unconfined compressive strength

1. INTRODUCTION

In general, the soil cement mixing techniques originally developed in the U.S. have been widely accepted in Japan for more than 30 years. Names such as Jet Grouting, Soil Mixing, Cement Deep Mixing (CDM), Soil Mixed Wall (SMW), Deep Soil Mixing, (DSM), Dry Jet Mixing (DJM), and Lime Columns are known to many. Each of these methods has the same basic root, finding the most efficient and economical method for mixing cement (or in some cases fly ash or lime) with soil (Broms, 1983; Huang, 1993; Miki, 1997; Terashi, 1997; Terashi, 2002; Ruenkrairergsa and Jaratkorn, 2001; Ruenkrairergsa and Passara, 1998; Jaritngam, 2002). In Thailand, it has been introduced since 1990s by both government and private sectors. Improving OAC by cement mixing is one of the methods whereby the OAC is mechanically mixed with cement to form OACC layer. This technique is widely employed for highway project because it can rapidly improve the soil strength and also is relatively safe to the environment. For old asphalt concretes, after mixing with cement and curing time for 1, 3, 7, 14 and 28 days, induce the higher UCS. OAC can be recycled for used as soil-cement base by mixing with appropriate amount of cement content (Ruenkrairergsa and Jaratkorn, 2001). From experimental data, the results for OAC mixing are presented and predicted by the multiple regression model.

2. SAMPLE PREPARATION

Samples of OAC were collected from the Highway Project in Bangkok and Udornthani province (Ruenkrairergsa and Passara, 1998). The basic characteristics of both materials are summarized in Table 1.

Table 1: OAC Properties before mixed

Soil Properties	Bangkok	Udornthani
Gravel, >2.000 mm (%)	84.59	80.76
Coarse Sand, 2.000-0.425 mm (%)	13.71	15.29
Fine Sand, 0.425 mm-0.075 mm (%)	1.69	2.95
Silt Clay, <0.075 mm (%)	0.01	1.00
Maximum Particle Size (mm)	76.20	38.10
Medium Size (D_{50}) (mm)	6.50	3.60
Liquid Limit, LL (%)	NP	NP
Plasticity Index, PI (%)	NP	NP
Specific Gravity	2.43	2.42
MDD (t/m3)	1.90	2.12
OMD (%)	3.2	4.23
Soil Classification, USCS	A-1-a	A-1-a
Soil Classification, AASHTO	GP	GP

In this paper, the samples of OAC were mixed with the Ordinary Portland cement type 1 at the percentage of 1, 3, 5 and 7 by weight of OAC. Modified compaction specimens were prepared for UCS tests at curing times of 1, 3, 7, 14 and 28 days, respectively. Mixed cement content in the mold 101.6 mm in diameter, then compacted to 5 layers of 25 percent. The OAC and cement were mixed together so as to make the required amount of optimum water content corresponding to different percentage of cement was added. The resulting mixture was compacted in the compaction mold. Specimens from the compaction mold were then extracted and were kept in plastic bags to prevent moisture loss until the days of curing as shown in Figure 1(a). Three specimens were prepared for each percentage of cement and curing time respectively. UCS tests were conducted in accordance with ASTM D1633-84 (see Figure 1(b)).

Figure 1: Unconfined compressive strength (UCS) test samples and set-ups

The strength of the OACC was determined with UCS tests. UCS test is a special form of triaxial test where confining pressure is zero. UCS test is generally performed on cylindrical samples. Load-deformation characteristics are measured to determine strength characteristics. The main advantage of UCS test is that it is a simple and quick laboratory test for measuring strength. To prepare UC specimens, molds of 101.6 mm in diameter and 140 mm in height were used.

3. RESULTS AND DISCUSSION

From experimental data, the results for OAC mixing are presented in Table 2. The experimental results with 40 tests represent the UCS during the 28 days after addition of water. The cement content (C_C), curing time (T) and optimum moisture content (OMC) are linearly dependent predictors of the strength of OACC.

Table 2: Results of UCS tests of OAC samples

C_C %	*T (day)*	*MDD (ton/m³)*	*OMC (%)*	*UCS (ksc)*
1	1	1.900	3.20	2.6
1	3	1.900	3.20	2.7
1	7	1.900	3.20	2.9
1	14	1.900	3.20	2.8
1	28	1.900	3.20	3.2
3	1	1.900	3.20	6.1
3	3	1.900	3.20	7.9
3	7	1.900	3.20	8.4
3	14	1.900	3.20	8.6
3	28	1.900	3.20	9.0
5	1	1.900	3.20	10.2
5	3	1.900	3.20	11.0
5	7	1.900	3.20	13.4
5	14	1.900	3.20	16.0
5	28	1.900	3.20	18.3
7	1	1.900	3.20	15.8
7	3	1.900	3.20	17.0
7	7	1.900	3.20	18.5
7	14	1.900	3.20	19.7
7	28	1.900	3.20	22.7
1	1	2.124	4.23	4.0
1	3	2.124	4.23	5.1
1	7	2.124	4.23	4.4
1	14	2.124	4.23	5.7
1	28	2.124	4.23	6.7
3	1	2.124	4.23	7.9
3	3	2.124	4.23	8.9
3	7	2.124	4.23	9.8
3	14	2.124	4.23	11.2
3	28	2.124	4.23	11.7
5	1	2.124	4.23	11.3
5	3	2.124	4.23	13.1
5	7	2.124	4.23	13.7
5	14	2.124	4.23	17.2

5	28	2.124	4.23	18.5
7	1	2.124	4.23	16.3
7	3	2.124	4.23	18.4
7	7	2.124	4.23	18.7
7	14	2.124	4.23	20.2
7	28	2.124	4.23	23.5

Note: C_C = the cement content, T = the curing time, *MDD* = maximum dry density (ton/m^3), *OMC* = optimum water content (%), *UCS* = unconfined compressive strength (ksc)

The multiple regression model (Draper, N.R. and Smith H., 1998; Jaritngam, S. et al., 2013) was proven to have a good fit with inclusion of all the two predictors (unconfined compressive strength and the modulus of elasticity) presented as given in Equation (2).

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3}, i = 1, 2, ..., n \quad (2)$$

Where, y_i = the predictors (*UCS*), β_i = numerical constants and x_{ii} = soil cement parameters. In this model, multiple regression analysis is applied to all data. The resulting regression is as follows:

For unconfined compressive strength:

$$UCS = -0.324 + 2.527C_C + 0.169T \quad (R^2=0.948) \quad (3)$$

$$UCS = -5.644 + 2.527C_C + 0.169T + 1.432OMC \quad (R^2=0.963) \quad (4)$$

Where, unconfined compressive strength (*UCS*) unit: kg/cm^2, cement content (C_C) unit: % by weight, curing time (T) unit: days, dry density (D_D) unit: ton/m^3. optimum water content (*OMC*) unit: %

The maximum absolute error percentage of unconfined compressive strength was shown in Table 3 for all test samples. Comparison between the experimental data and predicted values obtained from Equation (3) was presented in Figure 2.

Table 3: Comparison of USC values from tests and multiple regression analysis model

Item	USC(tested) (ksc)	USC (predicted) (ksc)	Absolute error value	Absolute percentage error(%)
1	2.60	2.37	0.23	8.8
2	2.70	2.71	0.01	0.4
3	2.90	3.39	0.49	16.8
4	2.80	4.57	1.77	63.2
5	3.20	6.94	3.74	116.7
6	6.10	7.43	1.33	21.7
7	7.90	7.76	0.14	1.7
8	8.40	8.44	0.04	0.5
9	8.60	9.62	1.02	11.9
10	9.00	11.99	2.99	33.2
11	10.20	12.48	2.28	22.4
12	11.00	12.82	1.82	16.5
13	13.40	13.49	0.09	0.7
14	16.00	14.68	1.32	8.3
15	18.30	17.04	1.26	6.9
16	15.80	17.53	1.73	11.0
17	17.00	17.87	0.87	5.1

18	18.50	18.55	0.05	0.3
19	19.70	19.73	0.03	0.2
20	22.70	22.10	0.60	2.7
21	4.00	2.37	1.63	40.7
22	5.10	2.71	2.39	46.9
23	4.40	3.39	1.01	23.0
24	5.70	4.57	1.13	19.8
25	6.70	6.94	0.24	3.5
26	7.90	7.43	0.47	6.0
27	8.90	7.76	1.14	12.8
28	9.80	8.44	1.36	13.9
29	11.20	9.62	1.58	14.1
30	11.70	11.99	0.29	2.5
31	11.30	12.48	1.18	10.4
32	13.10	12.82	0.28	2.2
33	13.70	13.49	0.21	1.5
34	17.20	14.68	2.52	14.7
35	18.50	17.04	1.46	7.9
36	16.30	17.53	1.23	7.6
37	18.40	17.87	0.53	2.9
38	18.70	18.55	0.15	0.8
39	20.20	19.73	0.47	2.3
40	23.50	22.10	1.40	6.0

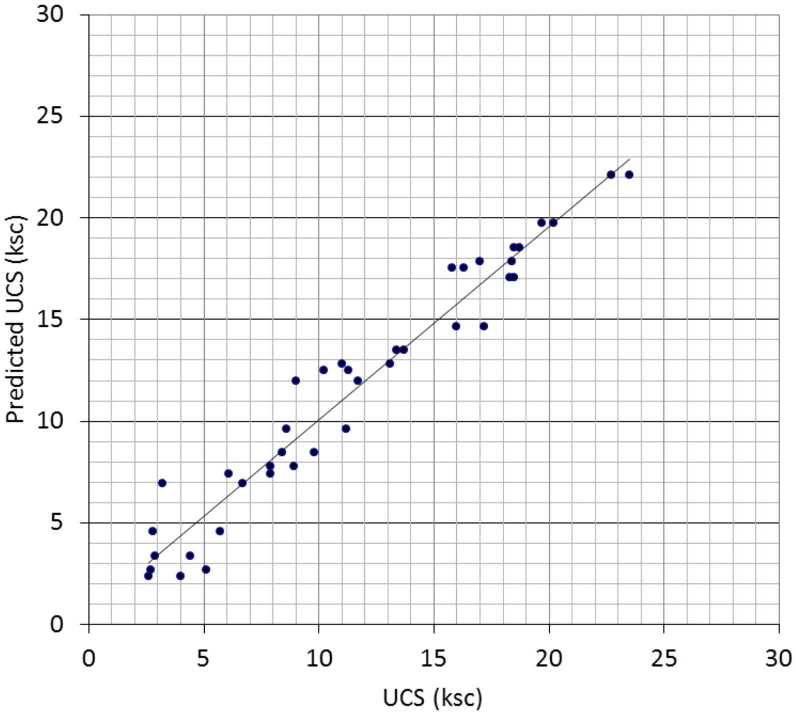

Figure 2: Comparison of tested vs. predicted values of USC

The coefficient of determination (denoted by R^2) is a key output of regression analysis. It is interpreted as the proportion of the variance in the dependent variable that is predictable from the independent variable. The coefficient of determination ranges from 0 to 1. An R^2 of 0 means that the dependent variable can not be predicted from the independent variable. An R^2 of 1 means the dependent variable can be predicted without error from the independent variable. An R^2 between 0 and 1 indicates the extent to which the dependent variable is predictable. Therefore, 96% of the variability in UCS is explained by the developed multiple regression Equation (4).

4. CONCLUSIONS

With the addition of cement contents to OAC material from road pavement, the mixture exhibits an increase in UCS values. Based on the results of the study, the following conclusions can be drawn:

- Multiple regression models can be used to predict the strength of OACC more easily and efficiently since it is more user-friendly.
- The higher the percentage of cement added the higher the increment in the strength of treated OAC.
- Cement content (C_C) and curing time (T) have major effects on the UCS strength of OACC.
- On the basis of the results, 3% cement content is the optimum for use as a base course in highway pavements.
- The performance evaluations showed that the multiple regression model predictions are very satisfactory in estimating unconfined compressive strength.

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