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Technical and Economical Evaluation of Cold Recycled Asphalt Using Emulsified Asphalt Binder through Response Surface Method

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ABSTRACT: One of the common recycling methods of asphalt is the reuse of crushed asphalt with cement as a reinforcement of the base layer and its replacement in pavement layers. In this research, cold recycling of asphalt using emulsified asphalt binder has been investigated through the response surface method. In this regard, the technical and economic aspects of 15 fabricated samples of recycled cold asphalt mixtures using crushed asphalt materials, cationic emulsified binder and Portland cement (type II) were investigated. Marshall strength and flow, real specific weight and air void percentage of the mixture were determined by experiments. By performing an analysis of variance on the proposed models and determining the effective parameters, mathematical equations between independent and dependent parameters were developed and the effect of the parameters was investigated. Finally, an optimum mix design, which has 60% desirability, was suggested for cold asphalt recycling.

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1- Introduction

The cold recycling of asphalt using crushed asphalt has long been common. The main purpose of asphalt recycling is to reuse materials to repair and improve the pavement. Today, due to economic savings, preservation of natural resources, elimination of previous damages, reduction of destructive effects on the environment, speed of work, etc., the tendency towards asphalt recycling has increased. One common method of recycling is to reuse crushed asphalt with binders as cold recycling. Another method is to use these materials, along with cement as a reinforcement of the base layer and its replacement in pavement layers.

So far, limited aspects of the mixing design of recycled cold asphalt mixtures have been presented. The purpose of this study is to investigate the technical characteristics of cold asphalt mixtures by response surface method and their economic evaluation. In practical studies in the field of civil engineering, the response surface method has been used dramatically. In the field of concrete technology, Murali et al. [1], Ray et al. [2] and Habibi et al. [3], in the field of soil mechanics Yuan et al. [4] and Tsang et al. [5], in the field of environmental engineering, Deng and Chen [6], and in asphalt technology, Hamzah et al. [7] and Abdullah et al. [8] were among the people who used the response surface method in the design and analysis of their experimental works.

2- Materials and methods

In this study, Design Expert software and response surface method were used to investigate the technical and economical behavior of cold recycled asphalt mixtures. The response surface method is a set of statistical techniques and applied mathematics for developing experimental models. The goal of this method is to optimize the response (output variable), which is affected by several independent variables (input variables). In this study, independent variables, including emulsified binder, cement and water, were defined. The minimum and maximum levels for these parameters are presented in Table 1. Dependent variables include real specific weight, air void percentage, Marshall strength and flow, and cost of preparing recycled cold asphalt mix. Table 2 shows the research experiment design.

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Table 1. Input variables and their values

Variable	Minimum value	Maximum value
Emulsified binder (%)	1	4
Cement (%)	0	2
Water (%)	2	4

Table 2. Designed experiments through the response surface method

Experiment	Emulsified binder (%)	Cement (%)	Water (%)
1	4	2	4
2	2.5	1	3
3	1	2	4
4	4	2	2
5	2.5	2	3
6	4	0	2
7	1	0	4
8	2.5	1	2
9	4	0	4
10	4	1	3
11	2.5	0	3
12	1	2	2
13	2.5	1	3
14	2.5	1	4
15	1	1	3
16	1	0	2
17	2.5	1	3

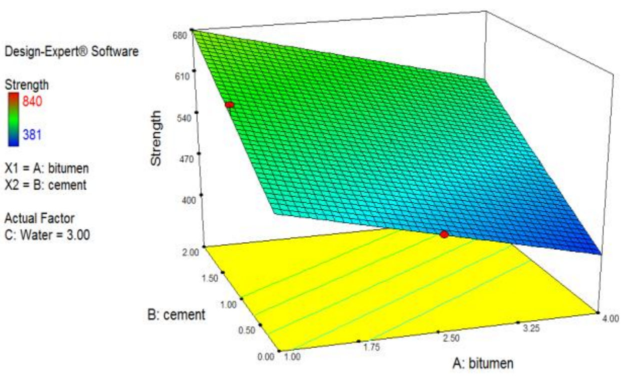

Fig. 1. Three-dimensional model of Marshall strength between cement and binder

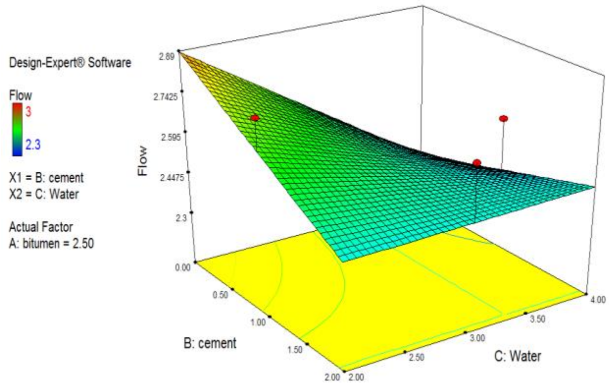

Fig. 2. Three-dimensional Marshall flow model between water and cement

3- Results and discussion

Figure 1 shows a three-dimensional graphical model of the relationship between the independent variables and the dependent variable for Marshall strength. As it is seen, with increasing the amount of cement from 0 to 2%, the Marshall strength increases with more slope, while with increasing the amount of binder from 1 to 4%, the strength decreases with a slight slope.

Figure 2 shows a three-dimensional graphical model of the relationship between independent variables and dependent variables for Marshall flow. As shown in the figure, by increasing the amount of cement from 0 to 2%, the Marshall flow decreases with a greater slope. Increasing the amount of water in 2% cement has no effect on Marshall flow. Such diagrams can be provided for other dependent variables of the research.

In order to obtain the optimal values of binder, cement and water, optimization was performed according to the criteria of publication No. 339. The allowable percentage of air void for cold recycled asphalt mixture is 9 to 14 (such as 11.5) percent recommended. Optimization was performed for maximum real specific weight, maximum Marshall strength and minimum cost. Marshall flow was considered to be 2 to 3 mm. In optimization, the desirability value for the optimal mixing design is 60%, which is shown in Table 3. Figure 3 shows the desirability diagram for the amounts of cement and binder.

4- Conclusions

In this study, by analysis of variance, a linear model was presented to predict the amount of Marshall strength, air void percentage, real specific weight and construction cost between independent and dependent variables. In Marshall flow Prediction, the proposed model is a two-factor model. Marshall strength increases with increasing the amount of binder and cement. As the amount of cement increases, the

Table 3. Optimal values of binder, cement and water and the results obtained from these values

Binder (%)	Cement (%)	Water (%)	Strength (Pa)	Flow (mm)	Air void (%)	Reald weight specific	Cost (Tomans)
2	1.16	4	573.2	2.42	11.94	2.12	53202.5

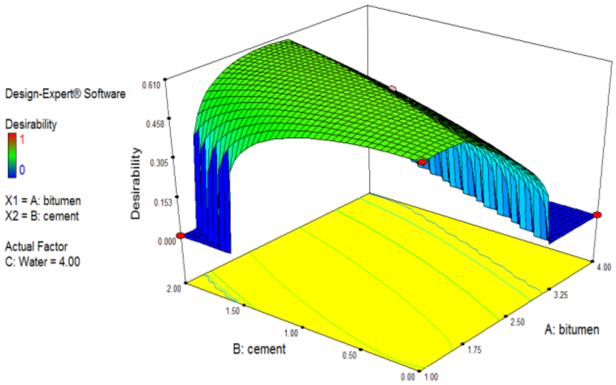

Fig. 3. Desirability diagram for cement and binder for the proposed mixing design

real specific weight decreases with a very small slope. In this study, the amount of binder, cement and water were defined as 2, 1.16 and 4, respectively, for the available materials and based on the response surface methodology.

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