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Prediction of the Asphalt Mixture Performance Prepared with Recycled Fine Aggregate by using Response Surface Analysis

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Applying new techniques such as numerical method would prepare more facilities to estimate the result of experimental studies.In this research, performance of asphalt mixtures prepared with recycled aggregates was measured by using response surface analysis method. For this aim, recycled aggregates obtained from chip seal roads were used as fine aggregates with new aggregates in asphalt mixtures. Recycled aggregates were added into the mixture with 25, 50, 75, 100% ratios. 50/70 and 70/100 penetration bitumens were used as binder in the prepared mixtures. In order to measure the perfromance of mixtures, Marshall stability, flow, cantabro were performed. The results obtained from response surface analysis showed that, the estimation models have R^2 values higher than 80. This means that, response surface analysis can be used as a numerical method for the prediction of asphalt mixture perfomance.

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1. Introduction

Increasing economic cost and lack of availability of natural materials have opened the opportunity to explore the local available recycled materials. Aggregate that is used in asphalt mixture is usually obtained from natural resources, such as basalt, granite and limestone which are exploited and processed into crushed stone with various sizes and specific gradation. Furthermore, daily utilization of natural materials and demolishing of structures, roll up the lack availability of virgin materials problem. Therefore, it necessitates the recycling material and use them almost as a substitution of virgin material. In the recent years with the development of science and technology, investigators try to use new methods such as response surface analysis (RSA) in order to analyze data obtained from the different tests easily.

RSA is well-known as a beneficial statistical analysis in modeling curvature effects in many scientific areas [1]. The effect of different amount of additive on fatigue life of asphalt which calculated with response surface method shows that, the fatigue life of specimens increased when the level of test strains decreased [2]. Effect of compaction temperature, rediset contents and asphalt binder contents on the volumetric and strength properties of warm asphalt mix have been evaluated by response surface method and show that, optimum bitumen content (OBC) of warm mix asphalt compacted at high temperature is higher than OBC of warm mix asphalt compacted at lower temperature [3]. The fracture toughness characteristics that affect the cracking performance of different asphalt mixtures can be calculated with response surface method and the result of this method show a good agreement with the expected data which confirm the appropriateness of the optimization process [4]. Response surface method has been conducted in the various investigations such as civil engineering [5–7], mechanical engineering [8] geotechnical engineering [9, 10] to evaluate material performance without too many experiments. In this study after the conducting various tests such as Marshall stability, flow, cantabro, performace of mix asphalt that obtained from the certain percentage of recycled aggregate, virgin aggregates and two different types of bitumen (70/100, 50/70) were evaluated by using RSA method.

2. Materials and equipments

Marshall stability that is the identifier of specimens resistance to plastic deformation under the maximum load at rate of 5 mm per minute was conducted in order to evaluate the specimens stability until failure, maximum load that leads specimens failure is Marshall stability and variation of specimens diameter is flow value. Cantabro test that its principle is determination percentage of specimens mass losses, carried out on the compacted samples, after the fulfillment 300 gyrations of Los Angeles machine at speed 30–33 rpm, mass losses of specimens were calculated by subtracting the mass of specimens before and after test. Moreover, Properties of asphalt mixture were inspected by the analyzing of voids fill with bitumen (VFB), air voids (V) and bulk specific gravity (BSG). The analysis of tests result was performed by using RSA

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with statistical analysis software (SAS). Recycled aggregate (25%, 50%, 75% and 100%) and two different types of binders (50/70 and 70/100) that formed the hot mixture were used as variables in the RSA, then experimental data were analyzed by RSA method. RSA estimation is expressed by a general quadratic model shown in Eq. (1):

$$Y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{1i}^2 + \beta_4 x_{2i}^2 + \beta_5 x_{1i} x_{2i} + \varepsilon_i \quad (1)$$

where, Y_i is calculated parameters of Marshall samples (Marshall stability, void etc.), x_{11} is is first statistically estimated model parameter; x_{2i} is statistically estimated model parameter; β_0 is the intercept; β_1, β_2, β_3, β_4, and β_5 are the interaction coefficients of linear, quadratic and second order terms, respectively; and ε_i is the error term. The closeness of model fit in Eq. (1) has been accepted as the coefficient of determination (R^2).

3. Results and discussion

Results of RSA that estimate the properties (void, VFB, BSG) and performance (stability, flow, mass-loss) of mixtures which formed with 4 different RRA rates and two different types of binder are shown in Table I.

TABLE I

Response surface analysis results.

Dependent	Parameter	DF	estimate	std err	t value	probt	R^2
Void	Intercept	1	8.268571	0.442156	18.70	< 0.0001	0.9839
	RRA	1	0.002154	0.010327	0.21	0.8430	
	BITUMEN	1	−0.758000	0.273215	−2.77	0.0392	
	RRA*RRA	1	−0.000105	0.000075414	−1.39	0.2220	
	BITUMEN*RRA	1	−0.015360	0.004462	−3.44	0.0184	
	BITUMEN*BITUMEN	0	0	–	–	–	
VFB	Intercept	1	59.133000	4.277925	13.82	< 0.0001	
	RRA	1	−0.118600	0.099911	−1.19	0.2885	
	BITUMEN	1	−1.214000	2.643391	−0.46	0.6653	
	RRA*RRA	1	0.000948	0.000730	1.30	0.2505	
	BITUMEN*RRA	1	0.125720	0.043166	2.91	0.0333	
	BITUMEN*BITUMEN	0	0	–	–	–	
Stability	Intercept	1	9.091429	0.722274	12.59	< 0.0001	0.9160
	RRA	1	−0.014234	0.016869	−0.84	0.4373	
	BITUMEN	1	−0.362000	0.446304	−0.81	0.4542	
	RRA*RRA	1	−0.000103	0.000123	−0.83	0.4418	
	BITUMEN*RRA	1	−0.001040	0.007288	−0.14	0.8921	
	BITUMEN*BITUMEN	0	0	–	–	–	
B.S. Gravity	Intercept	1	2.318286	0.005686	407.74	< 0.0001	0.9938
	RRA	1	0.000097143	0.000133	0.73	0.4973	
	BITUMEN	1	0.022000	0.003513	6.26	0.0015	
	RRA*RRA	1	0.000003429	0.000000970	3.54	0.0166	
	BITUMEN*RCA	1	0.000160	0.000057371	2.79	0.0385	
	BITUMEN*BITUMEN	0	0	–	–	–	
Marshall Flow	Intercept	1	2.772000	0.105835	26.19	< 0.0001	0.9957
	RRA	1	0.014080	0.002472	5.70	0.0023	
	BITUMEN	1	0.374000	0.065397	5.72	0.0023	
	RRA*RRA	1	0.000056000	0.000018051	3.10	0.0268	
	BITUMEN*RRA	1	−0.001440	0.001068	−1.35	0.2354	
	BITUMEN*BITUMEN	0	0	–	–	–	
Mass-Loss	Intercept	1	40.375714	9.348971	4.32	0.0076	0.8192
	RRA	1	−0.664897	0.218345	−3.05	0.0286	
	BITUMEN	1	−15.522000	5.776863	−2.69	0.0435	
	RRA*RRA	1	0.004677	0.001595	2.93	0.0325	
	BITUMEN*RRA	1	0.087120	0.094336	0.92	0.3981	
	BITUMEN*BITUMEN	0	0	–	–	–	

The R^2 values of response surface for recycled aggregates and bitumen type that used as variation shows the estimation properties and performance values of Marshall samples. As it seems in Table I, R^2 values are quite high. This shows that estimation models quite reliable in predicting Marshall sample's properties and performance especially in the Marshall flow and BSG values which obtained 99%. The results obtained from RSA has indicated that the estimation models have high R^2 values (higher than 81%) which could be used for predicting properties and performance of samples. In addition, Fig. 1 shows the response surface charts of these analyzes.

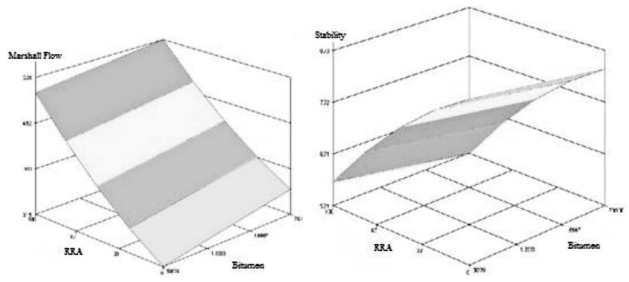

Fig. 1. Response surface charts.

4. Conclusion

Since the experimental studies are based on the parameters of high cost and long-term of work, these parameters increase with the increasing number of experiments. So, nowadays new methods that is being followed by investigators can evaluate input data easier and faster. In the method of RSA first, a certain number of experimental studies are carried out and then the possible experiment results are statistically estimated. Therefore, the suitability of the parameters which used to obtain the results of experimental studies is very important. In this study, successful prediction rate was obtained through RSA ($R^2 \geq 81$). On the basis of these results, the response surface analysis that obtained in this study in order to predict the asphalt mixture performance was considered reasonable. It concluded that RSA can be used as a numerical method for the prediction of asphalt mixture performance due to the high value of R^2.

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