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Investigate the Moisture Damage Mechanism in Asphalt Mixtures Using Thermodynamic Parameters and Mixing Design

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ABSTRACT: Moisture damage in asphalt mixtures is defined by loss of strength and durability due to water availability. The lack of correlation between the damage mechanism in the laboratory and the field conditions, the lack of measurement of the effective properties of the materials and their role, the lack of a corrective strategy and other shortcomings of existing laboratory methods to determine the moisture sensitivity has led researchers in recent years to consider providing methods based on effective parameters in damage events. Accordingly, this study is an attempt to provide a prediction model of moisture sensitivity using thermodynamic parameters and mixing design that can predict and analyze the asphalt mixture's performance against moisture. 24 different combinations of asphalt mixtures have been investigated using three types of aggregate with different performance against moisture, two types of asphalt binder and three types of additives in this study. The surface free energy components of asphalt binder and aggregate were measured using a sticky drops and a general absorption device, respectively. To provide a prediction model for the performance of the moisture sensitivity of asphalt mixtures, the simulation of the conditions according to AASHTO T283 standard has been used and the indirect tensile resilient modulus test in dry and wet conditions has been performed. The results of this research indicate that the use of anti-stripping additives can generally improve the performance of asphalt mixtures against moisture, but the type and percentage of these additives should be determined according to the type of aggregate, the type of asphalt binder and the properties of the mixing plan for asphalt mixture. According to the proposed model, it can be said that the parameters of cohesive free energy, adhesive free energy of asphalt binder-aggregate in dry conditions, the coating of aggregates by asphalt binder, the specific surface area of the aggregates and the apparent thickness of the asphalt binder membrane on the aggregate surface directly and the energy released by the system during the occurrence of stripping, the percentage of saturation and the permeability of the asphalt mixture, inversely affect the asphalt mix's strength against moisture damage.

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1. Introduction

Moisture damage can be defined as loss of strength and durability in asphalt mixtures caused by the effect of moisture. In general, moisture damage can be divided into two main processes:

1- Loss of adhesion, and

2- Loss of cohesion [1].

Loss of adhesion is due to the fact that water is placed between asphalt binder and aggregate. Due to the greater tendency of aggregate to water compared to its tendency for asphalt binder, the layer of asphalt binder is removed from the aggregate surface. The loss of cohesion is due to the fact that the relationship between asphalt binder and water changes the asphalt binder properties, which causes the asphalt binder to be separated from the aggregate surface or the failure of the asphalt binder membrane. Moisture damage can be due to either of these two processes or a combination of both [2].

The most important studies conducted on moisture damage in asphalt mixtures are the study of known processes called stripping. Stripping is the process of separating asphalt binder from the aggregate surface [3]. External factors are parameters that examine conditions outside the asphalt mixture system, such as traffic and weather fluctuations [4]. Some of the most important external factors that affect moisture damage include production, performance, traffic levels and environmental conditions. Dampness of transported aggregates from bonds, inappropriate drying, non-homogeneous mixing, improper loading of asphalt mixture on the truck, density, longitudinal seams, weight and number of roller passes [5, 6].

The performance of hot asphalt mixtures against moisture is a complex issue, and there has been the subject of several investigations over the last six decades. During this period, technicians and researchers from laboratories, research institutes and road construction agencies have carried out a variety of experiments in an attempt to achieve a reliable test that is consistent with the results of field performance of asphalt mixtures. Of course, the fact that the adhesion between asphalt binder and aggregate decreases in the presence of water and the cohesion within the asphalt binder due to moisture disappears has long been evident to the asphalt mixture performers [7].

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Among different researchers, the development of a method for evaluating the moisture susceptibility of asphalt mixtures that can distinguish between asphalt mixtures with weak or strong performance has become a challenge. The available methods for determining the moisture sensitivity of asphalt mixtures are mainly based on comparing the mechanical properties of asphalt mixtures in wet to dry conditions. Despite the widespread use of these tests, their use is associated with a number of problems, most notably the following:

1- Failure to measure fundamental properties of materials,

2- Failure to provide reasons and damage mechanism,

3- Failure to provide an appropriate corrective solution, and

4- The lack of expression of the effects of additives.

2. Methodology

In this study, in order to provide a predictive model of moisture sensitivity based on free surface energy parameters and mixing design, the relationship between the effective parameters in the event of moisture damage and the results of moisture sensitivity experiments of asphalt mixtures on the samples made in the laboratory has been used. In this research, 6 types of aggregate have been used. In fact, three types of base aggregates used in this study are modified using calcium nanocarbonate coverage and used as aggregates. The reason for using different aggregates is to investigate the effect of the mineralogy structure on the moisture sensitivity properties of asphalt mixtures.

3. Results and Discussion

The results of the resilient modulus ratio in wet to dry conditions are investigated based on the type of asphalt binder and the saturation percentage of the samples in two different percent saturation. Addition of anti-stripping materials has been able to improve the resilient modulus ratio of base asphalt mixtures.. As can be seen from the data presented in Table 1, the coefficient of determination for the model presented in this study was 0.920, which is a statistically significant amount.

Table 1. Summing up the results of the resilient modulus ratio model

Model	Multiple correlation coefficient (R)	Coefficient of determination (R2)	Adjusted coefficient of determination	Estimated standard error
Multiple regression	0.951b	0.916	0.904	1.7998

In the following table, the coefficients of the multiple regression model along with the coefficients of significance tests are presented. The cohesion free energy, adhesion free energy, specific surface area and apparent thickness of the asphalt binder membrane have a positive effect on increasing the strength of the asphalt mixtures against moisture.

Table 2. Moisture damage prediction model coefficients based on the resilient modulus ratio

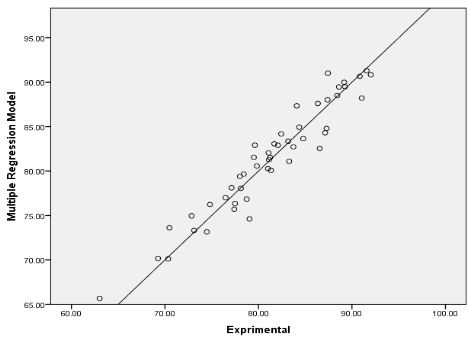
Model	Non-standard coefficientS		P-value
	Coefficient (B)	Standard error	
Constant number	44.434	10.418	0.000
Cohesion free energy	1.051	0.118	0.000
Adhesion free energy	0.175	0.062	0.007
Debonding energy	-0.317	0.065	0.000
Specific surface area	14.859	2.807	0.000
Permeability	-0.040	0.010	0.000
Apparent thickness of the asphalt binder membrane	1.617	0.364	0.000
Saturation percentage	-0.227	0.016	0.000

Based on the proposed coefficients, it can be said that the moisture damage prediction regression model based on the resilient modulus ratio is:

$$RMR = 44.434 + 1.051\,CE + 0.175\,AE - 0.317\,DE + 14.859\,SSA - 0.040\,PA + 1.617\,AFT - 0.227\,DS \quad (1)$$

Where RMR = resilient modulus ratio from 0 to 100, the magnitude of this parameter indicating a higher strength of the asphalt mixture against moisture damage, CE = cohesion free energy of asphalt binder (ergs/cm2), AE = adhesion free energy between asphalt binder-aggregate (ergs/cm2), DE = debonding free energy (ergs/cm2), SSA = specific surface area of aggregates (m2/gr), PA = permeability of asphalt mixture (µm/sec), and AFT = Asphalt Film Thickness of asphalt binder membrane on aggregate surface (µm), and DS (dynamic stability) = saturation percentage of mixed asphaltic samples (%).

The percentage of use of nano zinc oxide and liquid amine materials is 5000 and 500 tomans, respectively, to add up the



cost of one ton of asphalt mixtures. This figure is about 3700 tomans for coating aggregate with calcium nanocarbonate. If the cost per ton of asphalt is about 150000 tomans, the use of nano zinc oxide, amine liquid and calcium nanocarbonate add 3, 0.3 and 2.5 percent at a cost per ton of asphalt mixtures. The amount of resilient modulus in the dry condition under the influence of the above mentioned materials was 5.6, 4.5 and 4.7, which equally reduces the thickness of the asphalt mixture. Accordingly, it can be said that the use of these materials will not only reduce the cost of making asphalt mixtures, which will even reduce costs.

4. Conclusions

Based on the activities mentioned in order to achieve the objectives of this research, the results have been obtained, the most important of which are given below.

1- The increase in parameters of cohesion free energy, adhesion free energy, specific surface area and apparent thickness of asphalt binder membrane has improved the strength of asphalt mixtures against moisture in the model presented in this study.

2- The increase in parameters of permeability, saturation percentage and debonding energy significantly negatively affects the strength of asphalt mixtures against moisture damage.

3- In the model presented on the basis of the resilient modulus ratio, it is observed that the saturation percentage and cohesion energy respectively have the greatest role in reducing and increasing the strength of asphalt mixtures against moisture.

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