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“Research Note”

USE OF ULTRASONIC PULSE VELOCITY (UPV) FOR ASSESSMENT OF HMA MIXTURES BEHAVIOR[*]

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Abstract– Non-destructive methods are nowadays widely used to evaluate the performance of structures and infrastructures, including pavements. In this paper, Ultrasonic Pulse Velocity (UPV) test is investigated for evaluation of the behavior of Hot Mix Asphalt (HMA) mixtures. The effect of different mixtures parameters, including gradation, bitumen and filler contents are studied by means of indirect computation of Elastic modulus of HMA from UPV test and its comparison with experimentally derived Stiffness modulus values from Indirect Stiffness Modulus (ITSM) test.

Keywords– UPV test, HMA, stiffness modulus, Young’s modulus

1. INTRODUCTION

Many factors affect the mechanical properties of HMA mixtures, such as the percent of fractured particles (F.P %), bitumen content, temperature, gradation and filler content [1, 2]. Based on the literature, it would be useful to study the relation between Stiffness Modulus (SM) and UPV test parameters. For this purpose, the first step is to investigate the effect of different mix parameters and the accuracy of results presented by UPV. The purpose of Non-Destructive Test (NDT) methods is to obtain information on a given structure without causing any destruction or damage to the investigated area. Various NDT methods have been developed and applied in engineering with varying degrees of success [3-5]. Current wave-based NDT methods, such as UPV, impact echo, and spectral analysis of surface waves (SASW), have been used for the evaluation of material properties. In this study, the variation of UPV test results of HMA mixtures with regard to changing the gradation, filler and bitumen contents of mixtures were investigated. Assessment of the UPV test results were done by means of a comparison of the indirectly derived Young’s modulus of the HMA specimens from the UPV test and their stiffness modulus from ITSM test.

2. EXPERIMENTAL PROCEDURES

The binder was selected to be 60-70 penetration degree asphalt binder, produced by Isfahan Refinery, Iran. The penetration test was carried out since it is the standard used in Iran, although many countries are moving toward performance grade designation. The properties of used bitumen were tested and were all within the limits defined for 60-70 asphalt cement by the standards [6]. Two types of gradations were used and shown in Table 1, which is in accordance with Iranian standards for roads and pavements to study the effect of mix parameters [7]. For each gradation, two different quantities of F.P. (100% and 90%) were employed. Fractures Particles content is the percentage of fractures particles to the total coarse aggregates

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(size greater than 4.75 mm) in the HMA (ASTM D 5821) [6]. Three filler (Portland cement) contents of 3, 5 and 7% were used with each gradation. Marshall Compaction method has been employed for preparation of the samples (ASTM D6926-04) [6].

Table 1. Gradations used in this study

Sieve size	3/4”	1/2”	3/8”	#4	#8	#16	#30	#50	#100
Type 1	100	95	79	59	43	31	25	13	11
Type 2	100	100	92.5	55	22.5	15	-	4	-

The ultrasonic test system used in this study operates in the through-transmission mode. It consists of a pair of 70 mm diameter platens containing the transducers, a pulse-generator, and a receiver. The pulser is excited by a single voltage spike of 100 V. To transmit the wave through the specimen, platens containing the crystals were placed firmly against the surface of the material. A metal frame was used to prevent eccentricity-related errors. An electronic clock, which automatically displays the wave transmission time in a range from 0.1 to 9999 micro-seconds, was employed to measure the wave arrival time. In order to determine the elastic constants, elasto-dynamics theory was used. Even though asphalt concrete is a visco-elastic material, the theory of elasticity can be used since the displacements and corresponding strains are very small and the actual movements are very short in duration. This is a reasonable assumption because the tests were conducted at 25˚C. For the sake of simplicity, the asphalt mixture can be assumed to be a homogenous, isotropic solid [8-9]. A frequency of 55 kHz was recently employed by Birgisson et al. to evaluate the changes in HMA integrity due to moisture [8]. In this study, a 54 kHz frequency ultrasound wave was used to test asphalt concrete specimens. This frequency was recently employed by the authors [9, 10]. In all cases, the aggregates size was checked to be less than the wavelength (λ) which we have as λ = Pulse velocity/Frequency of vibration. A series of Indirect Tensile Stiffness Modulus (ITSM) tests were carried out on the specimens by means of a Nottingham Asphalt Tester (NAT) to elaborate on the mechanical changes of the different mixtures used and also to compare the mechanical behavior presented by the UPV test with that of an established test. A value of 0.35 for Poisson’s ratio was found to be reasonable for asphalt mixtures at about 25°C, in accordance with ASTM-D4123 [6].

3. DISCUSSION OF THE RESULTS

Young’s modulus was calculated based on the density of the specimens and the S- wave and P-wave velocities as follows:

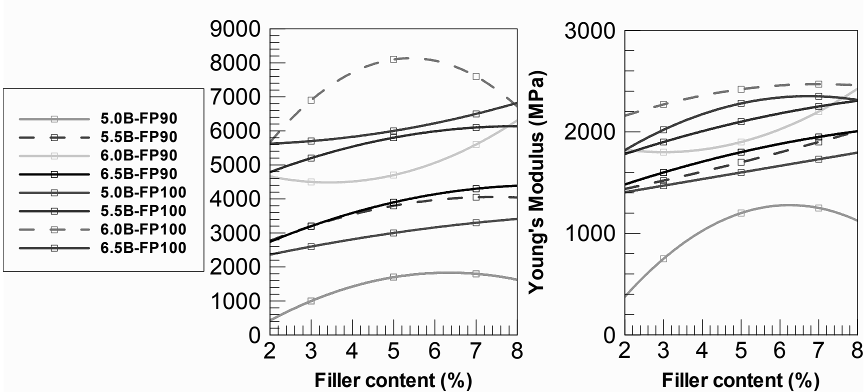
$$V_s = \sqrt{\frac{E}{2\rho(1+\upsilon)}} \tag{1}$$

$$V_p = \sqrt{\frac{E(1-\upsilon)}{\rho(1+\upsilon)(1-2\upsilon)}} \tag{2}$$

$$E = \frac{\rho V_s^2(3V_p^2 - 4V_s^2)}{V_p^2 - V_s^2} \tag{3}$$

where E is Young’s modulus in Pa; ρ is the density in kg/m^3; V_p is the compression wave velocity in m/s; and V_s is the shear wave velocity in m/s.

The results are presented in Fig. 1 for gradations types 1 and 2. The ITSM tests were conducted parallel to the UPV tests to compare the two descriptions of mechanical behavior. Stiffness Modulus (SM) or Resilient can be determined from the ITSM test and is actually an estimate of HMA modulus of elasticity (E). While the modulus of elasticity is stress divided by strain for a slowly applied load, SM is stress divided by strain for rapidly applied loads. SM values from the ITSM test results indicate that there is good agreement between the parameters obtained by UPV and the results from the ITSM test. Related non-linear regression curves have been developed that exhibit very high R^2 (about 0.93) and showed a marked rise in Young's modulus in the relevant optimum bitumen content. Statistical analysis showed that the consistency coefficient for different studied mixtures varies in the range of 0.87 to 0.99. Thus, the wave velocities through the asphalt concrete specimen present a meaningful trend.



a) Gradation 1 b) Gradation 2

Fig. 1. Young's modulus variations for gradation group types 1&2 (B and FP in legends mean bitumen and fractured particles contents of each sample and are followed by their percentage values(%))

Bitumen content of 5.9% for gradation type 1 with 3% filler content, 6% for the same gradation and 5% filler and about 6.2% for the same gradation with 7% filler were found to be the optimum bitumen contents. Similar studies were undertaken to determine the optimum bitumen contents of the specimens from the type 2 gradation group. The results indicate that the optimal bitumen content rises in comparison to that of the gradation type 1. The filler stiffens the binder, which is reflected in the observation that E increases in most cases with increasing the filler content. Additional specimens were tested to obtain more precise results. On the basis of these results, it was recognized that the peak value of Young's modulus occurred at a bitumen content close to the optimum bitumen content of the mixtures. For all bitumen contents, the specimens with greater F.P% exhibit a greater Young's modulus (*E*). There is a balance between achieving higher density and higher *E*. If a mix has high shear resistance due to a high fraction of fractured particles, it is more difficult to compact, which could reduce density while keeping *E* higher. The presented effective range of filler content could be discussed on the basis of the Rheological impact of filler content for HMA mixtures. Some deviations from the presented amount were observed in the case of different F.P% for each group of gradations. This could be because interlocking particles of the gradation with 90% F.P are held weakly together in comparison to those of 100% F.P gradation, and therefore, different voids are provided. Similar studies were undertaken on the type 2 gradation, and those results are also presented in Fig. 2.

As a result of the wide range of type 1 gradation in comparison to that of type 2, the optimal bitumen content, at which the greatest value of both shear and P-wave velocities occur, increases for gradation type 2.

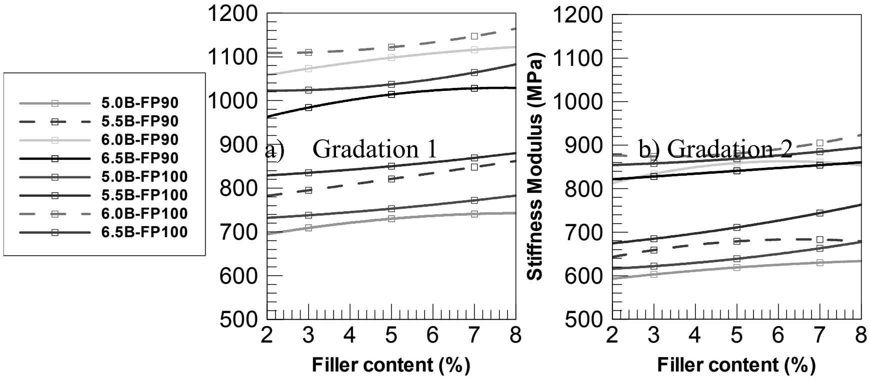


Fig. 2. Stiffness modulus variations for gradation group types 1&2-Marshal compaction

4. CONCLUSION

- For all of the mixtures with different percentages of fractured particles and filler content, a specific bitumen content could be determined at which the wave velocities exhibit a marked rise and after which both velocities start to decrease.
- For a determinate gradation, increasing the filler content increases the small strain Young's modulus obtained from UPV test and both shear and P-wave velocities. The bitumen content at which the maximum Young's modulus (also the stiffness modulus) occurs markedly increases with greater filler content.

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