Engineering Characterization of Hot-Mix Asphalt in Western Australia

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Abstract

The use of full depth asphalt pavement to construct and rehabilitate heavily loaded urban roads that has grown rapidly in Western Australia over the past 3 years. Five different types of asphalt mixes were produced in the laboratory according to the Australian Standard methods of sampling and testing asphalt to modify payment performance mixture. The main role of this research is to evaluate and assess the hot-mix asphalt pavement performance characteristic for Western Australia road. In this study, laboratory test for tensile strength, resilient modulus, wheel tracking, asphalt binder content and Marshall Compaction test were taken and analyzed to each asphalt mixtures. Results showed that AC20-75 and AC14-75 Blow asphalt mixes were more efficient and effective in pavement performance as compared to the other mixes. In general, all the asphalt mixes that are used in this study can strength and stable the mixture stiffness of asphalt that is notable. The modification effect rank can be described as AC20-75 Blow > AC14-75 Blow > AC14-50 Blow > AC7-50 Blow > SMA7-50 Blow in this research.

Author keywords: Characteristic; asphalt mixture; hot-mix asphalt; tensile strength; resilient modulus; wheel tracking; asphalt binder content; Marshall compaction; Western Australia

1. Introduction

The use of full depth asphalt pavements to construct and rehabilitate heavily loaded urban roads has rapidly grown in Western Australia (WA) over the past 3 years. There is limited data available from testing carried out by the Mainroads about the characteristics and variability of WA asphalt mixes. Although some data is available from testing carried out by others on Mainroads contracts, but it also would be necessary to determine whether Mainroads WA owns this data and has the right to publish the data so that it can be used to predict the likely performance of WA full depth asphalt pavements.

Hot-mix asphalt is known by many different names: HMA, asphaltic concrete, plant mix, bituminous mix, bituminous concrete, and many others (Gillespie et al. 1992) . It is a combination of two primary ingredients – aggregates and asphalt binder. The aggregates total approximately 95% of the total mixture by weight. They are mixed with approximately 5% asphalt binder to produce HMA (Gillespie et al. 1992). Hot and cold asphalt mixes are comprised of two major materials: aggregates (i.e. mixture of sand, gravel, crushed stone, slag and mineral filler) and asphalt cement (crude oil, hydrated lime and dust) as discussed on literature by (ACIC2007; Mrawira & Luca 2006). Bitumen had been defined by various sources as crude oil with a dynamic viscosity at reservoir conditions more than 10,000 centipoise (AASHTO1986; ACIC2007).

The asphalt concrete or hot mix asphalt (HMA) is the one the most widely used infrastructure materials for road construction. Hot mix asphalts can be described as a multiphase heterogeneous material composed of a viscoelastic asphalt binder, irregular rigid aggregate particle in high volume fraction, and small percentage of air voids (Gopalakrishnan & Kim 2011). These component materials exhibiting various properties contribute to complex mechanical behavior of HMA, which can be characterized as viscoelasticity, and plastic under different condition such as temperature, load application and aging (Dibike et al. 2001). Therefore, the mechanical behavior of hot mix asphalt should be understood by not only the individual properties of HMA components, but also by considering asphalt binder and aggregate acting together.

The goal of this study is to evaluate and assess the engineering chacteristics of hot-mix asphalt using a laboratory tests so that data can be used to predict the likely performance of Western Australia full depth asphalt pavement. Figure 1 shows the different types of asphalt mixes in this study.

(a) SMA7-50 Blow **(b) AC7-50 Blow** **(c) AC14-50 Blow**

(d) AC14-75 Blow **(e) AC20-75 Blow**

Figure 1: Types of asphalt mixes during the laboratory tests

2. Materials and Methods

2.1 Materials

Types of hot mixed asphalt used on the Mainroads WA network are dense graded asphalt (DGA), open graded asphalt (OGA) and stone mastic asphalt (SMA). DGA, the most common type of asphalt, provides optimal structure strength and generally good resistance to deformation. OGA is designed to drain water through the asphalt to remove excess water from the tyre/road surface. SMA is similar to OGA but has a high proportion of dust and high binder contents to achieve an improved fatigue life. SMA has a texture surface but does not drain water through its layer as does OGA (ACIC2007; Brown, Kandhal & Zhang 2004; MRWA2007). All Materials selected for this project were from local sources and are indigenous of Western Australian pavement materials used in the industry.

2.2 Methods

The design method specified by Mainroads Western Australia is the Marshall method of mix design. The aim of the method is to satisfy specified design criteria. The descriptions of asphalt mixes design are as following:

- SMA7-50 blow: thickness of 7 mm granite stone mastic asphalt (SMA)
- AC7-50 blow: thickness of 7 mm open graded granite
- AC14-50 blow: thickness of 14 mm dense graded granite (intersection mix)
- AC14-75 blow: thickness of 14 mm dense graded granite (intermediate mix)
- AC20-75 blow: thickness of 20 mm dense graded granite (intermediate mix)

During individual asphalt mixes run, specimens were taken and assessed in different categories of asphalt mixes. Asphalt mixes specimens were subjected to the laboratory tests: tensile strength (TSR), resilient modulus, wheel tracking, asphalt binder content and Marshall Compaction test.

The bulk specific gravity test was performed after samples had cooled to room temperature according to the Australian Standard Testing Method AS 2891. Air voids were calculated using bulk specific gravity and maximum theoretical specific gravity data. Three specimens for each asphalt mix were tested as per Australian Standard. Specimens were placed in a water bath at 60^{o}C for a period of 30 min and were tested for Marshall Stability and flow. The details methods of sampling and testing of hot-mix asphalt in Australian Standard Testing Method are shown in Table 1.

Table 1: Methods of sampling and testing asphalt in Australian Standard Test Method (Austroads 1992; Austroads 2006; Austroads 2008)

Type of Mix	Material Test	Test Method
SMA7-50 Blow	Tensile strength ratio	AGPT/T232
AC7-50 Blow	Resilient modulus	AS 2891.13.1
AC14-50 Blow	Wheel tracking	AGPT/T231
AC14-75 Blow	Asphalt binder content	AS 2891.1.1
AC20-75 Blow	Marshall compaction	AS 2891.9.3

3. Engineering Characterization of Asphalt Mixes

3.1 Tensile Strength Ratio

A variety of test have been used that attempt to identify the moisture sensitivity and binder stripping potential of asphalt mixes. The test was carried out according to AASHTO T283 (commonly known as the Modified Lottman Test) specification by loading a Marshall specimen with compressive loading acting parallel to and along the vertical diametric-loading plane (AASHTO1986). The ratio of the tensile strength of the water-conditioned specimens to that of dry specimens is the tensile strength ratio. Tensile strength ratio (TSR) of asphalt mixes is an indicator of their resistance to moisture suitability In Australia, the development and implication of practical fundamental and simulative tests for characterization potential of asphalt mixes-tensile strength ratio test has implemented on AG:PT/T232, adapted from ASTM D 4867-92 (Austroads 2008).

3.2 Resilient Modulus

The resilient modulus is defined as a ratio of the deviator stress to the recoverable strain. It is known that the bituminous material is not elastic, but it experiences some permanent deformation after each load application (Jahromi & Khodaii 2009). Resilient modulus of pavement material is an important material property in any mechanistically based design/analysis procedure for flexible pavements (FHWA2002). The resilient modulus (M_R) is the material property required for the 1993 American Association of State Highway and Transportation Officials (AASHTO) Design Guide, which is an empirically based design procedure, and is the primary material input parameter for the 2002 Design Guide (AASHTO1993).

3.3 Wheel Tracking

Australia initially adopted the dynamic creep test as the preferred method of determining the rut resistance of asphalt mixtures (Austroads 2008). Currently, wheel tracking is selected as the most suitable test method for measuring the rut resistance of asphalt mixtures (Olive & Alderson 1995a). The wheel tracking test consists of a loaded wheel assembly and a confined mould in which a 300×300×200 mm specimen of asphalt mix is rigidly restrained on its four sides. A motor and a reciprocating device provide the forward and backward motion to the wheel at the rate of 24 passes per minute along the length of the slab. The temperature during the test is maintained by a water bath over and around the mould.

3.4 Asphalt Binder Content

The flexural stiffness and fatigue life of asphalt also influence by the binder volume (film thickness) and compaction level (air void) achieved in the mix. The combined effect of binder content and air voids in a mix in the form of percent voids filled binder (VFB) has also been considered as an useful parameter in the fatigue life predication models (Harvey et al. 1995; Said 1997; SHRP1994b). Santucci (1977) applied a correction factor to estimate the fatigue lives of mixes with binder and air void contents other than the mixes with $V_b = 11\%$ and $V_a = 5\%$, evaluated controlled stress fatigue tests.

3.5 Marshall Compaction of Hot-Mix Asphalt Pavement

The compaction process has a great effect on the strength and durability of hot-mix asphalt pavements. The main objective of pavement compaction is to achieve an optimum density. This helps to ensure that pavement will have the necessary bearing capacity to support the expected traffic loads and durability to withstand weathering (Chadbourn et al. 1996). The goal of compaction is to achieve the optimum air void content and compressing the coated stones together by increasing the density of the mix to the considered level of compaction with a minimum change in the gradation and structure (Airey et al. 2008; Pourtahmasb & Karim 2010).

Recent laboratory studies have shown that the compaction can highly affect the performance of the hot-mix asphalt (HMA) and stone mastic asphalt (SMA) mixtures (Khan et al. 1998; Linden, Mahoney & Jackson 1992). Inappropriate compaction may draw the binder to the surface of HMA and SMA causing flushing of the surface and loss of texture or aggregate segregation (Pourtahmasb & Karim 2010). California kneading compactor, Gyratory compactor and Marshall Hammer are being used as SMA compactors due to mix design method (Khan et al. 1998).

4. Results

A summary of average tensile strength ratio of dry and moisture condition is shown in Table 2. From the data presented, it can be seen that the AC7-50 blow asphalt mix has generally had high TSR of 112.9% as compared to other asphalt mixes. AC20-75 blow was the second best to have nearly reached a TSR of AC7-50 blow. This showed that the asphalt mixes are non-moisture susceptible. SMA7-50, AC14-50 and AC14-75 blow asphalt mixes had also relatively low as compared to AC7-50 and AC20-75 blow asphalt mixes but both of them are not susceptible to moisture. According to AASHTO T283,"Resistance of Compacted Bituminous Mixture to Moisture Induced Damage", the design asphalt mixture is judged to be non-moisture susceptible if it has a TSR greater than 80 percent (Airey et al. 2008; AASHTO2000; Apeagyei, Buttlar & Dempsey 2006).

The average resilient modulus for different types of asphalt mixes is given in Table 3 and Figure 2. As it can be seen from the results, AC20-75 blow asphalt mix had high resilient modulus of 6824 MPa (Figure 2). However, SMA7-50 and AC7-50 blow asphalt mix had poor resilient modulus of 3713 and 4618 MPa, respectively (Figure 2). It is clear that asphalt mix that has low resilient moduli do tend to contribute to low plasticity, low group index, high silt content, low clay content, low specific gravity, and high organic contents. Hicks and Monismith (1981) stated that the resilient modulus of partially crushed aggregate decreased with an increase in fine contents, while the modulus increased for crushed aggregate with increasing in fine content. The total recovered strain (Figure 3), rise time and temperature (Table 3) of the resilient modulus test for each asphalt mixes are similar. This showed that the resilient modulus is based up within the determination of Australian Standard.

The average wheel tracking test for different types of asphalt mixes is shown in Figure 4. The analyses indicated that AC20-75 blow asphalt mix had low rut depth of 1.9 mm as compared to other asphalt mixes. AC14-75 blow was the second in rank with a rut depth of 2.4 mm. This showed that these asphalt mixes are high rut resistance of asphalt mixture and less to pavement distress and asphalt fatigue cracking. However, the rut depth observed for SMA7-50 blow was 15 mm after 8, 452 cycles while 5 mm and 4.2 mm for AC7-50 blow and AC14-50 blow after 10,000 cycles, respectively. This indicated that SMA7-50 blow asphalt mix has high pavement distress and low rut resistance of asphalt mixture. There was also a sudden steep change in slope after 8,000 cycles for SMA7-50 blow. This may be attributed to the stripping of aggregate. No stripping was however, observed after 10, 000 cycles to other asphalt mixes.

A summary of asphalt binder content for different types of asphalt mixes is shown in Figure 5. The results indicated that AC14-75 and A20-75 blow property of asphalt mix had low percentage of binder content of 4.7% and 4.3% in the given order. This showed that AC14-75 and AC20-75 blow asphalt mixes might have increased the frictional contact between aggregate particle and the overall stiffness and stability of the asphalt mixes as compared to other asphalt mixes. However, SMA7-50, AC7.50 and AC14-50 blow asphalt mixes had high percentage of binder content. This showed that increase in binder content reduce the frictional contract between aggregate particles. Beyond a certain value, further increases in binder content reduce the frictional contact between aggregate particles and the overall stiffness and stability of the asphalt (Austroads 2006). At low percentages, added binder content increases the mix cohesion and strength (Anderson, Walker & Turner 1999).

Average Marshall Compaction stability and Marshall Compaction flow for different types of asphalt mixes are shown in Figure 6 and 7. As it can be seen from the analyses, AC20-70 blow asphalt mix had high stability of 16 kN (Figure 6) as compared to other asphalt mixes. AC7-50, AC14-50 and AC14-75 blow asphalt mix had a similar strength and stability of 15.1 kN. This indicated that the asphalt mixes pavement will have the necessary bearing capacity to support the expected traffic loads and durability to withstand weathering. Marshall Compaction flow rate for AC20-75 blow was less as compared to other asphalt mixes (Figure 7). However, SMA7-50 blow had poor strength and stability and high Marshall Compaction flow of 5.3 mm, and can highly affect the pavement performance. Recent laboratory studies have shown that the compaction can highly affect the performance of the hot-mix asphalt mixtures (Linden, Mahoney & Jackson 1992; Pourtahmasb & Karim 2010).

5. Conclusions

The pavement materials performance for strength and durability of hot mix asphalt mixtures was assessed and analyzed using the engineering characteristics and variability of flexible pavement for Western Australia roads in laboratory tests.

The comparison of the different types of asphalt mixes using a standard tests methods and techniques revealed that an AC20-75 blow and AC14-75 blow asphalt mix are the most efficient and effective in all categories of engineering characterization and variability of asphalt performance measures for strength and durability as compared to other asphalt mix.

In general, all the asphalt mixes that are used in this research study can strength and stable the mixture stiffness of asphalt that is notable. The modification effect rank can be described as AC20-75 Blow > AC14-75 Blow > AC14-50 Blow > AC7-50 Blow > SMA7-50 Blow in this research.

Table 2: Tensile strength (dry and moisture) for different types of asphalt mixes

Moisture Sensitivity						
Rank	**Mix**	**Tensile strength (kPa)**		**TSR (%)**	**Air void ratio (%)**	
		Dry	**Moisture**		**Dry**	**Moisture**
3	SMA7 - 50 Blow	686.9	626.6	91.2	8.0	7.9
1	AC7 - 50 Blow	831.5	938.7	112.9	8.2	8.3
4	AC14 - 50 Blow	990.4	894.8	90.3	8.4	8.2
5	AC14 - 75 Blow	1225.5	995.7	81.2	8.3	8.5
2	AC20 - 75 Blow	995.4	1024.8	103	7.8	7.4

Table 3: Resilient modulus for different types of asphalt mixes

Resilient Modulus Results							
Mix Type	**Specimen No.**	**Force (N)**	**Total Recovered (μ□)**	**Rise time (ms)**	**Load time (ms)**	**Resilient modulus (MPa)**	**Temp (°C)**
SMA7 – 50 Blow	1	717.8	48.5	40.0	138.8	1525.0	24.8
	2	1846.8	52.7	36.0	121.2	3600.0	24.6
	3	1942.1	52.1	36.8	119.8	3825.0	24.5
AC7 – 50 Blow	1	2627.1	54.2	38.0	121.4	5019.0	25.1
	2	2120.3	51.9	36.4	118.0	4223.0	25.3
	3	2338.0	52.3	36.6	117.6	4615.0	25.1
AC14 – 50 Blow	1	2694.6	52.1	39.8	122.8	5337.0	25.1
	2	2577.8	54.0	40.2	123.6	4921.0	24.8
	3	1315.1	53.0	35.2	127.6	2584.0	24.9
AC14 – 75 Blow	1	2902.7	52.1	39.0	122.0	5630.0	24.8
	2	2831.8	48.3	37.2	119.8	5959.0	25.2
	3	2865.5	52.1	36.8	119.8	5576.0	24.8
AC20 – 75 Blow	1	3244.2	48.8	45.6	133.6	6991.0	24.9
	2	3301.9	51.2	39.0	119.8	6794.0	24.6
	3	3361.7	52.0	42.2	123.6	6688.0	24.5

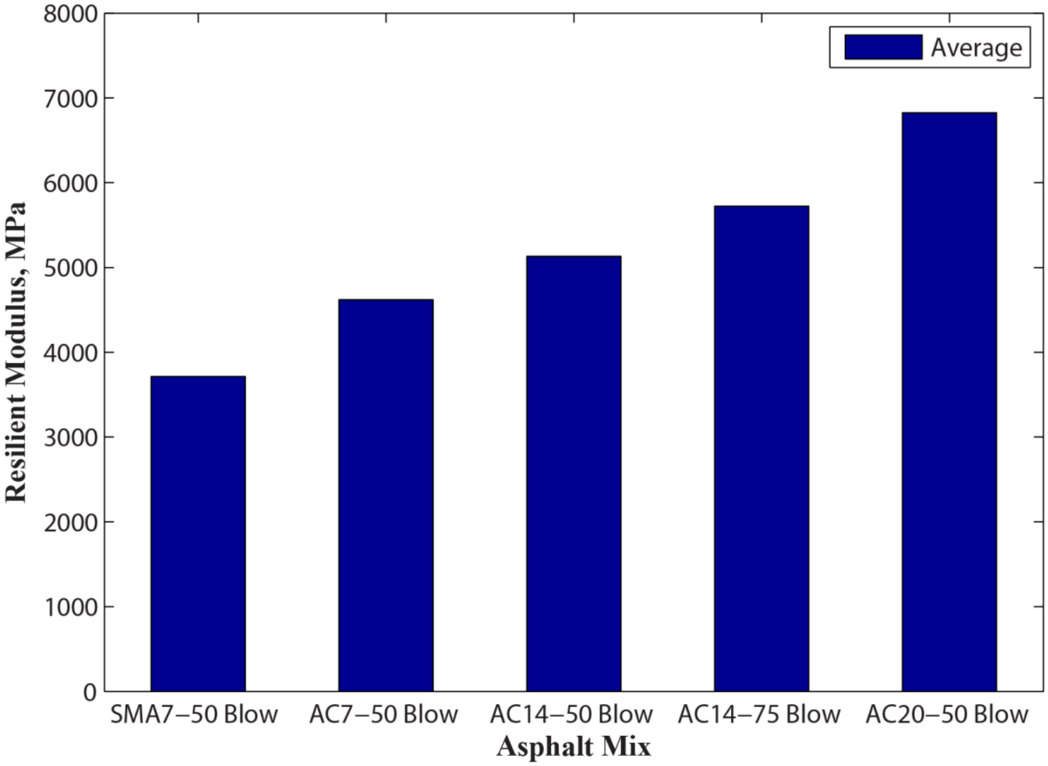

Figure 2: Average resilient modulus (air voids) for different types of asphalt mixes

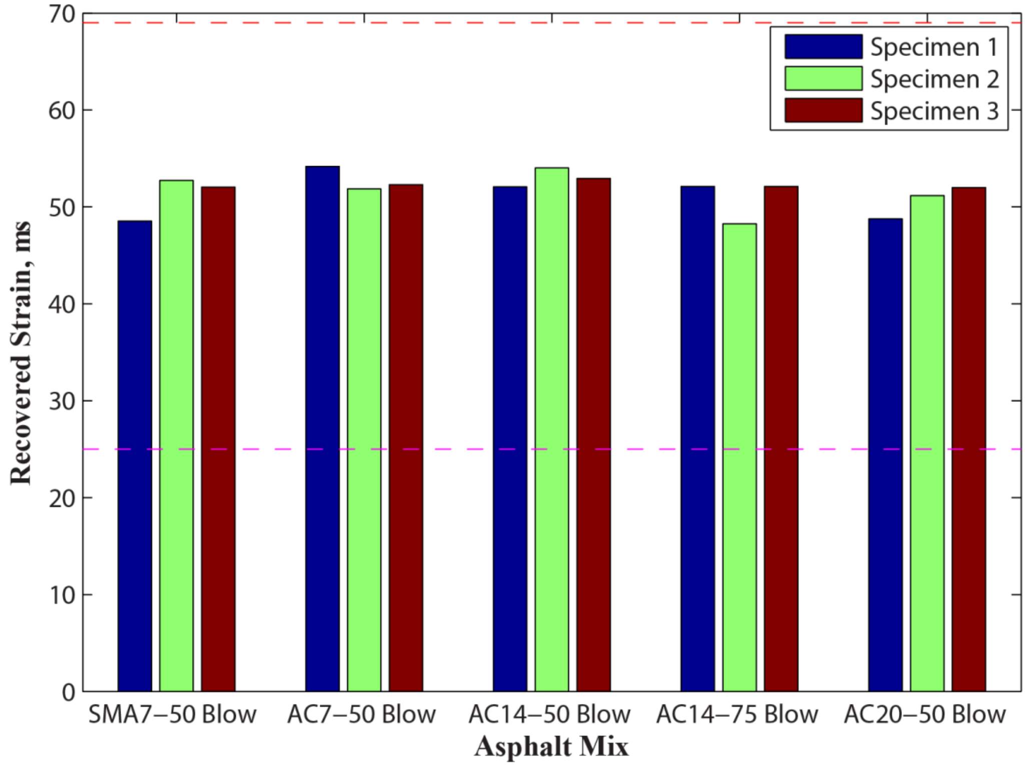

Figure 3: Resilient modulus (recovered strain) for different types of asphalt mixes

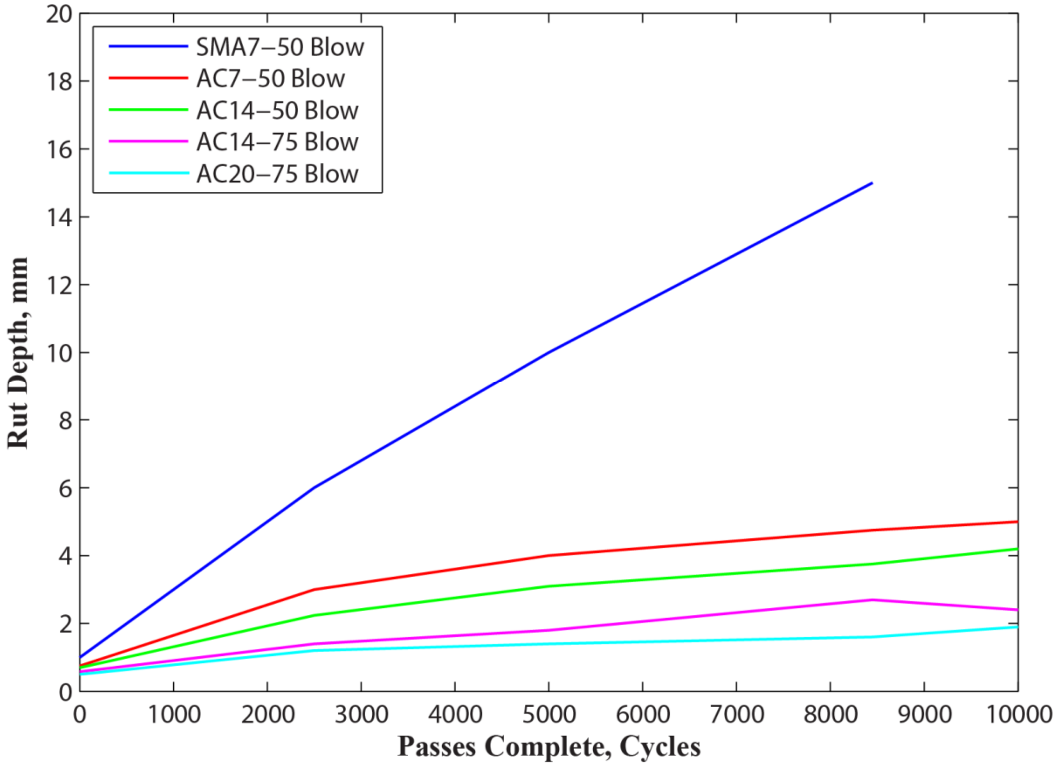

Figure 4: Average wheel tracking tests for different types of asphalt mixes

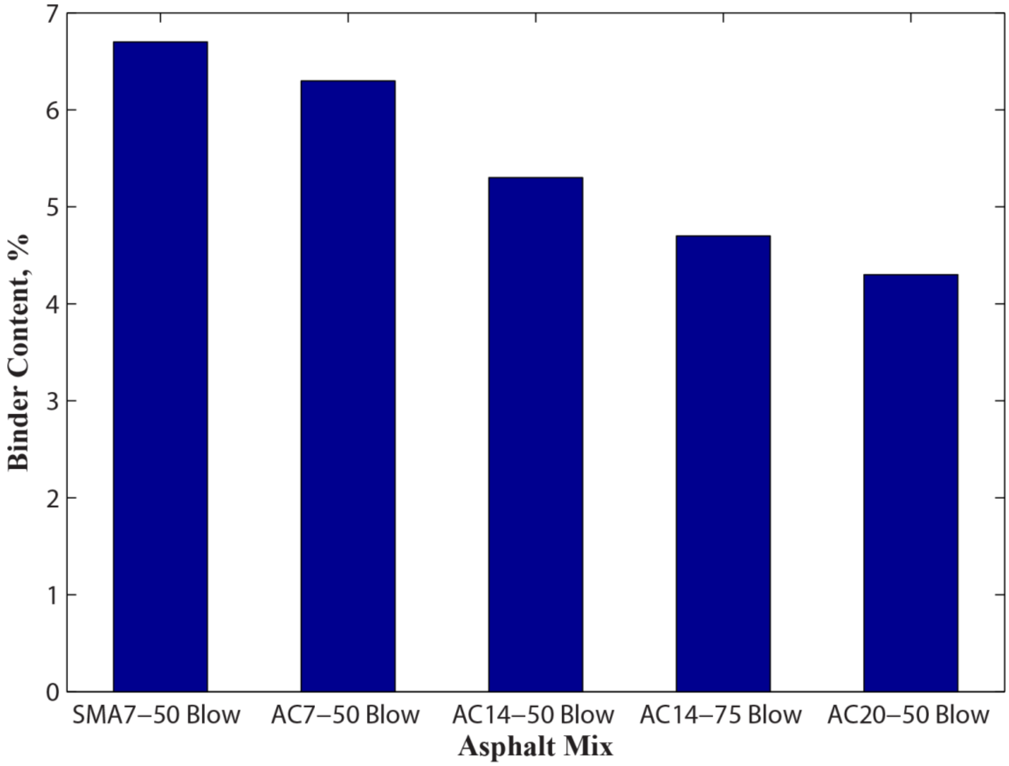

Figure 5: Asphalt binder content for different types of asphalt mixes

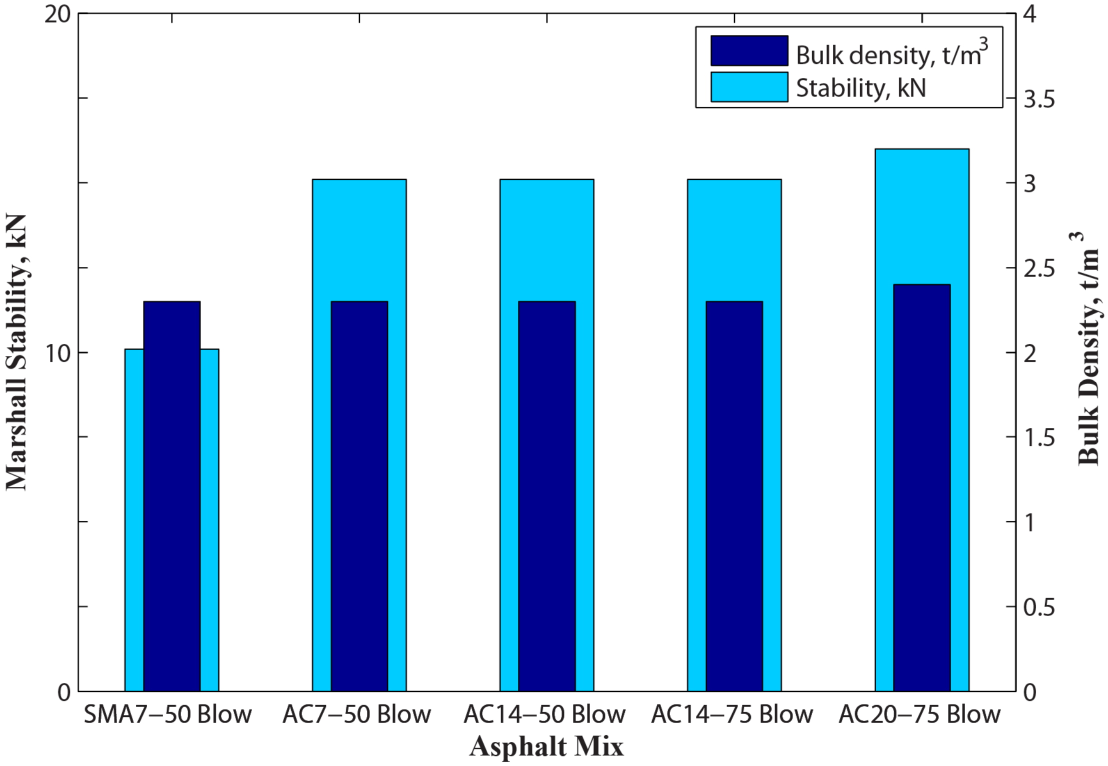

Figure 6: Average marshal compaction stability and bulk density of the different types of asphalt mixes

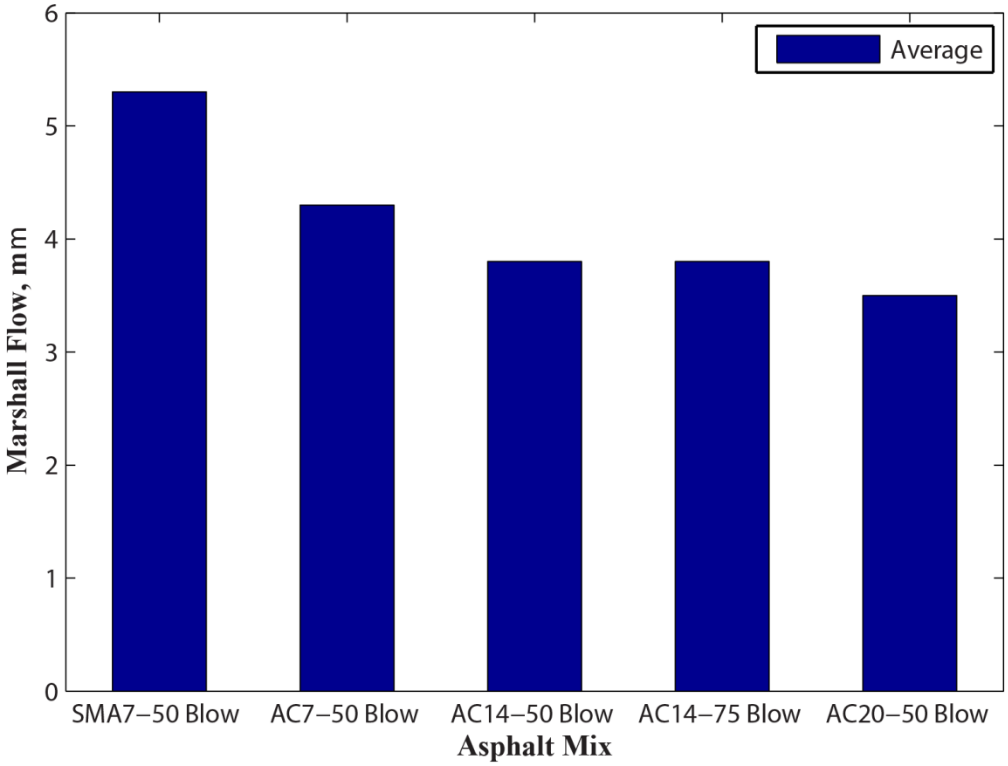

Figure 7: Comparison of Marshall Compaction flow in different types of asphalt mixes

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