Use of plastomeric additives to improve mechanical performance of warm mix asphalt

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ABSTRACT

A number of asphalt modifiers are known to improve the engineering characteristics of asphalt mixtures. However, asphalt mixtures produced with Polymer Modified Bitumen (PMB) are sometimes difficult to handle, and in many cases need higher mixing and compaction temperatures whereas the asphalt industry strives to reduce these temperatures in order to decrease energy consumption and harmful emissions of typically used Hot Mix Asphalts (HMA). This paper investigates if plastomeric materials (or a combination of elastomeric and plastomeric materials) can lead to better mechanical properties while reducing the processing temperatures. It shows that some low molecular weight poly-olefins having low viscosities above their melting point can act as processing aids and change the initial/inherent aggregate structure of the mixture (i.e., aggregates' packing) during compaction. This effect has been obtained with or without combination of elastomeric modifiers. The improved aggregate packing observed using image analysis tool ("iPas2") has a significant impact on performance-related properties like rutting resistance and complex modulus. Moreover, when the oxidized poly-olefins are used in the PMB, the polymer modified mixture appeared to be less sensitive to moisture damage as measured in water boiling tests and in modified Lottman test (ITSR).

Keywords: Additives, Compaction, Mechanical Properties, Modified Binders, Warm Asphalt Mixture

Introduction

The quality and quantity of the asphalt binder play significant roles in the performance of the entire pavement structure. In order to construct more durable pavements, appropriate asphalt binder selection is necessary in the prediction of hot mix asphalt performance. The more demanding specifications set forth by road regulation agencies, which specify and control some of the important physical properties of asphalt mixtures, require asphalt binders to have improved characteristics. Using modifiers including plastomers, elastomers, etc. to improve the engineering properties of asphalt binders is recognized as one of the most effective technical solutions for enhancing the mechanical properties of asphalt mixtures [1, 2, 3, 4].

Moisture Damage stripping susceptibility, permanent deformation (i.e., rutting) and cracking (i.e., thermal and fatigue) are the three main problems associated with the performance of hot mix asphalt pavements. There are a number of modifiers that can be added to the asphalt mixtures that can provide a solution to one or more of these problems. Polymer modified binders have been used in the asphalt industry for more than sixty years with significant increase in their usage during recent years. Polymers that can be broadly categorized as Plastomers and Elastomers, play an increasingly important role in the asphalt industry and are the most technically advanced bitumen modifiers currently available [5, 6].

Asphalt binders are temperature-susceptible viscoelastic materials that flow at high temperatures and become brittle at low temperatures, and therefore temperature and rate of load application have a great influence on their behavior. Asphalt binder consistency and hence the ability to sustain and hold its fundamental bonding characteristics varies with temperature. Most of the unmodified asphalt binders lack the proper viscoelastic balance which is usually due to the absence of an effective elastic network created by molecular combination. It is hypothesized that this viscoelastic balance can be formed by creating molecular association in an asphalt binder through the use of polymeric additives. An effective polymer improves the asphalt binder properties by creating a secondary network or new balance system within the asphalt binder which can happen through molecular interactions or reacting chemically with the binder [3, 6].

Hybrid modification is a term that is applied when two different types of modifiers are combined to produce an improved modification. The main interest in hybrid modification of binders is to capture the properties of the different modifiers. The hybrid binders have been introduced into the literature recently and thus only few studies on this topic are available. The objective of current study was to determine the effect of selected elastomeric and plastomeric additives and their combination on mixture performance.

Material used

Use of polymers is the most convenient way for Modified Binder producers and contractors to boost binder properties. The two most important classes of polymers are elastomers and plastomers. As an important category of plastomers, polyolefin is one of the earliest used modifiers for asphalt binder. Various polyolefin materials, including high-density polyethylene (HDPE), low density polyethylene (LDPE), linear low-density polyethylene (LLDPE), isotactic polypropylene (IPP) and a-tactic poly-propylene (APP) have been studied for application in bitumen modification due to the relatively low cost and the benefits they bring.

For this study, the following raw materials were used:

- One Pen 50/70 from Miro refinery. It served also as base bitumen for the preparation of the PMB.
- An oxidized low molecular weight HDPE (Honeywell Titan® 7686), described below as "Plastomer"
- A linear styrene-butadiene-styrene from Versalis, described below as "SBS or elastomer".

For one of the PMB prepared for the study, a combination of "Elastomer" and "Plastomer" was used. This type of binder is generically called "hybrid". The composition of the binders and their basic properties are given in Table 1. For comparison reasons, a commercial Pen 35/50 was also included in the study. These preliminary results indicate that the presence of plastomer boosts the high temperature performance (Softening Point) without negatively affecting the low temperature side (Fraass temperature). As could be expected, the plastomer by nature has a limited effect on the improvement of the elastic properties.

Table 1: PMB composition and properties

Property	Standard #	35/50	50/70	50/70 + 3% SBS	50/70 +2%SBS +0,8% Plastomer	50/70 +3% Plastomer
Penetration 1/10 mm	EN 1426	42	56	47	38	36
Softening Point, °C	EN 1427	52,0	49,1	54,8	56,4	67,3
Elastic Recovery @ 25°C, %	EN 13398	NA	NA	74	43	14
Fraass temperature, °C	EN 12593	NA	NA	-16	-19	-17

Mix design information

A Béton Bitumineux Semi Grenu (semi-course asphalt concrete) (BBSG) 0/10 Class 3 mix design was selected as this type of mixture is commonly used in France for heavy duty top layer. The design falls into the category of AC 10 SURF. According to EN 13108-1, the mix design includes the following tests: gyratory compactor, moisture sensitivity, rutting, stiffness and fatigue. The requirements are shown in Table 2.

Table 2: Requirements for a BBSG 0/10 Class 3 mix design

Property	Standard #	BBSG 0/10 Cl 3 Specs
Air Voids at 60 gyrations, %	EN12697-31	5-10%
Indirect Tensile Strength Ratio (ITSR), %	EN12697-12 B	> 75
Rutting at 30000 cycles and 60°C, %	EN12697-22	< 5,0
Stiffness at 15°C and 10 Hz, MPa	EN12697-26 A	> 7000
Strain corresponding to a fatigue life of 10^6 cycles at 10°C and 25 Hz (ε_6), µ.def	EN 12697-24 D	> 100

Aggregates used in these tests included granite and amphibole from Bonnefoy Beton Carrieres Industrie located at Courzieu – France, while the filler, limestone by nature, was supplied by MEAC also in France. The aggregate gradation is shown in Figure 1. The amount of binder in the mix was 5.35% by the weight of total mix. Samples containing the "plastomer" were mixed and compacted at lower temperatures than those used for the pure SBS mixtures as shown in Table 3. The temperatures were selected based on previous studies in which it was determined that using this source of plastomer allow more efficient compaction.

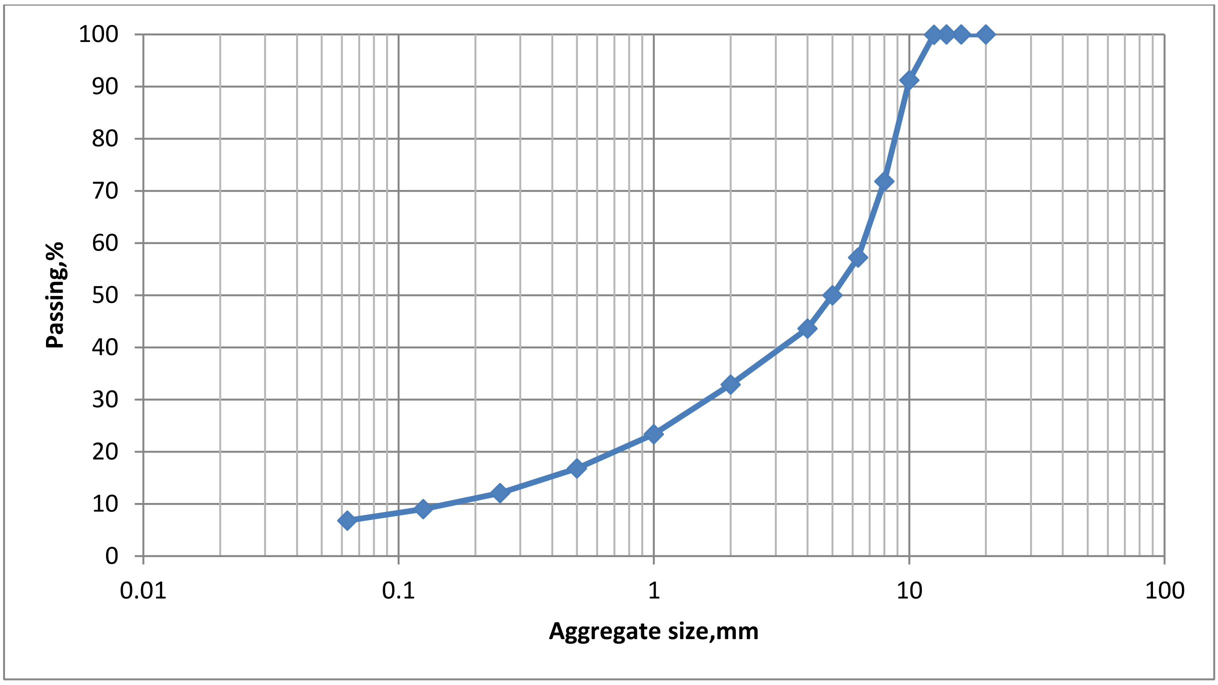

Figure 1: Gradation curve of the BBSG 0/10 Class 3

Table 3: Mixing and compaction temperatures

	35/50	50/70	50/70 + 3% SBS	50/70 +2% SBS +0,8% Plastomer	50/70 +3% Plastomer
Compaction temp, °C	165	150	185	175	155

Air voids measurements

The gyratory compactor was used to prepare sample for air voids measurements. Sample preparation is described in the EN 12697-31 standard. The gyratory compactor had a rotational speed of 6,3 RPM and applied an axial force of 15 KN. Samples had a diameter of 150 mm and were about 155 mm in height. An example of densification curve is shown in Figure 2.

The air voids at 60 gyrations as well as air voids at 10 and 200 gyrations are shown in Table 4. It can be seen that all mixtures meet the air voids requirements at 60 gyrations. The air voids after 200 gyrations are in the range 3,9% - 6,1%. These values may seem high but aren't unusual for Class 3 mixtures with a high rutting resistance.

It should be noted that mixes containing the "Plastomer" exhibit lower air voids than SBS and control mixes. In the other words, mixes containing the "Plastomer" are more workable than control and SBS mixes. As all mixes had an equal asphalt content of 5.35%, a lower air voids indicates either that asphalt content was high or that the compaction temperature was high. The generated results indicate that, for the mixes containing the "Plastomer", the compaction temperature can be further reduced (they were already lower than the SBS mix). In addition, test results also suggest that a reduction in the asphalt content could be considered for the "Plastomeric" mixes.

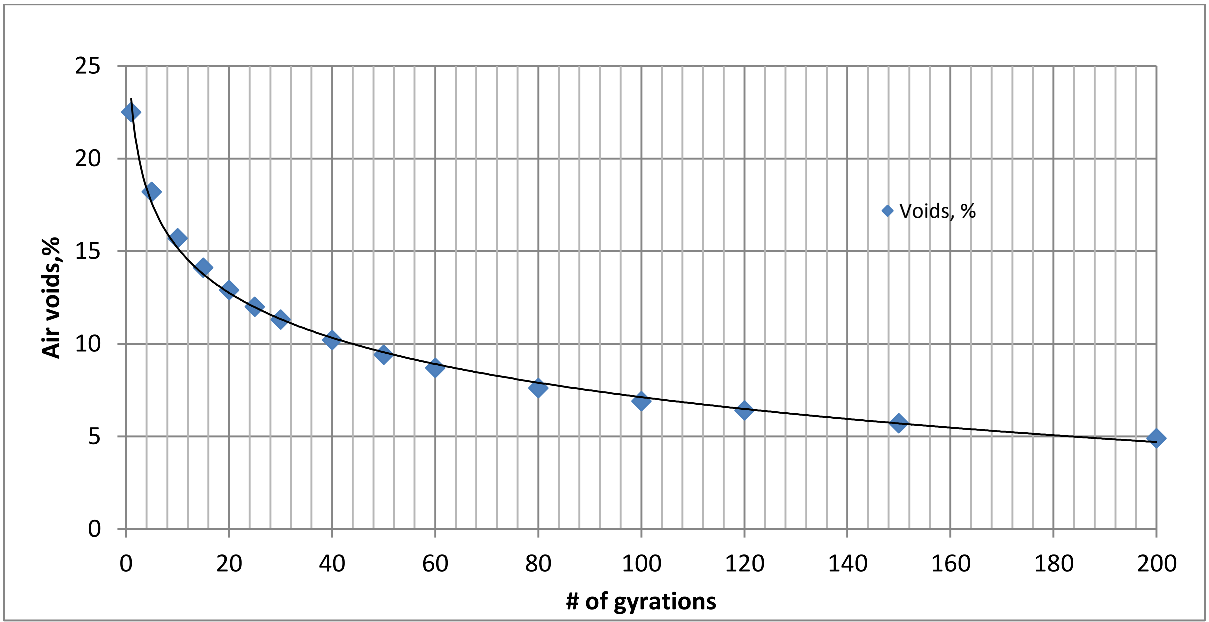

Figure 2: Example of a densification curve of the BBSG 0/10 Class 3

Table 4: Air voids at 1, 60 and 200 gyrations

	Pen 35/50	Pen 50/70	Pen 50/70 +3%SBS	50/70 +2%SBS +0.8% Plastomer	50/70 +3% Plastomer	Specifications
Testing temp, °C	165	150	185	175	155	
C1 voids, %	24,1	23,4	23,8	22,5	20,75	
C60 voids, %	9,4	9,7	10	8,7	7,2	5,0-10%
C200 voids, %	5,3	5,7	6,1	4,9	3,9	

Moisture sensitivity

Moisture sensitivity of an asphalt mixture was measured according to the EN 12697-12 standard (Duriez method). The effect of saturation and accelerated water conditioning on the indirect tensile strength of a cylindrical specimen is determined. Specimens were prepared by uniaxial compression using a force of 60 KN. Samples diameter was 80 mm. Compression tests were conducted on wet and dry samples at 18°C at a constant speed of deformation of 1 mm/sec. Prior to testing, samples were conditioned. For the dry conditioning, samples were keep at 20°C for 72 hr. The wet conditioning was performed by placing samples in water at 20°C and applying a vacuum to obtain an absolute pressure of 6,4 kPa. Conditioning lasted for 30 min. At the end of this step, samples were placed in a different container filled with water at 40°C and conditioned for another 72 hour. As shown in Table 5, the "Plastomeric" mixture and its hybrid version show excellent moisture damage resistance and higher strength values.

Table 5: ITSR test results

	35/50	50/70	50/70 + 3%SBS	50/70 +2% SBS +0,8% Plastomer	50/70 +3% Plastomer
Strength (Air), MPa	12	7,8	7,5	8,9	8,6
Strength (Water), MPa	10,4	7,6	6,8	8,4	8,1
ITSR (Water-Air), %	87	97	92	95	95
Void content, %	9,6	9,8	9,8	8,9	9,3

Water sensitivity was also assessed according to the Russian GOST 11508 standard where the coated samples are immersed for 1 hour in boiling water. Contrary to what has been done previously, the aggregate used for this experiment was North West Russian granite. The pictures of Figure 3 indicate that a low concentration of Plastomer (0,75%) already reduces the water sensitivity. This can be explained by the polar function of the selected "Plastomer".

Figure 3: Boiling water test results (left = pure SBS, middle = hybrid, right = pure plastomer)

Rutting resistance

The rutting resistance of the selected mixtures was measured according to the EN12697-22 standard with the large size device method. Samples were prepared according to the EN12697-33 (wheel fitted with pneumatic tires, heavy compaction level). Samples were prepared using mold with the following specifications: L=500 mm, l=180 mm, h=50 mm. Before the slab compaction phase, the exact quantity of mixture was added into the mold. Quality control indicated that air voids was equal to 7,9 ±0,05% for all specimens except for the 35/50 who had a lower void.

The following settings were used to measure the rutting resistance: wheel fitted with a 400x8 pneumatic tire without tread pattern and having a track width of 80 mm, tire pressure was equal to 600 kPa. The travel of the pneumatic tire relative to the specimen was equal to 410 mm. The frequency of travel was equal to 1 Hz and the load applied to the specimen was equal to 5 kN. Tests were conducted in air at 60°C and the rut depth at 3000 cycles are shown in Table 6. As shown, all mixtures but control 50/70 meet specification. In addition, it is shown that samples containing the "Plastomer" had the lowest rut depth.

Table 6: Rut depth results

	35/50	50/70	50/70 +3% SBS	50/70 + 2%SBS +0,8% Plastomer	50/70 + 3% Plastomer	Specs
Rut depth, mm after 30000 cycles in air @ 60°C	3,4	5,1	4,2	2,2	3,1	< 5,0
Void content, %	7,55	7,9	7,9	7,9	7,9	-

Stiffness

Stiffness was measured according to the EN12697-22 standard (indirect tension method). Slabs were prepared according to the EN12697-33, double wheel method. Cylinders having a diameter of 100 mm and a height of 70 mm were cored from the slab compacted samples. For the reason explained in the previous section, the air voids was rather uniform: all cored samples had an air voids between 7,5% and 7,6%. Repeated load pulses with rest periods (haversine waveform) were applied to the sample. The selected load was the one that gave a 5 µ-strain. The pulse was applied for 54 ms and measurements were conducted at 15°C. Test results for stiffness measurements are shown in Table 7. As shown, the mixes containing the "Plastomer" performed better than SBS and control 50/70 mixes and slightly underperformed the 35/50 mix.

Table 7: Stiffness test results

	35/50	50/70	50/70 + 3% SBS	50/70 +2% SBS +0,8% Plastomer	50/70 +3% Plastomer
Stiffness E*, MPa	12240	8398	8462	10389	9990
Void content, %	7,4	7,5	7,5	7,5	7,5

Fatigue

The fatigue life of mixtures was measured according to the EN 12697-24 (four-point bending method). Slabs were prepared according to the EN12697-33 (double wheel method). The specimens subjected to the test were obtained by sawing beams from slabs. Beams had the following dimensions: 62x10x10 cm. Test were carried out at 10°C applying a sinusoidal load with a frequency of 25 Hz. Tests were run in a strain controlled mode and three different strain (ε) levels were chosen in such way that the fatigue lives (N) were between 10^4 to $2x10^6$ cycles. For each strain level, two beams were tested. Linear regression lines were computed in a log N versus log ε plot. The strain corresponding to a fatigue life of 10^6 cycles (ε_6) and the slope of the fatigue life are the response parameters. The fatigue test results are shown in Table 8. Initial stiffness ($E^*_{initial}$) is also shown in the Table. As shown, all mixes meet the fatigue specification (ε_6>100 micro-strains – Log ε_6>2,00). Interestingly, while the mixtures modified with 50/70, SBS and the Hybrid gave a slightly higher log ε_6 (2,12-2,16) than the other mixtures (2,06-2,08), the slope of the fatigue life varies significantly based on the type of polymer used. It appears that for this mixture the Plastomer only gives the best performance (lowest slope value) followed by the 35/50 and the hybrid, indicating that this mixture modified with plastomer or hybrid polymers is less strain sensitive, and that at cycles higher than 1 000 000, the fatigue life ranking could be in favor of the Hybrid and the Plastomer. Sensitivity to strain level and cycles as indicated by the slope is very important as truck loading and number of trucks could vary a lot during pavement life.

Table 8: Fatigue test results

	35/50	50/70	50/70 + 3% SBS	50/70 +2%SBS +0,8% Plastomer	50/70 +3% Plastomer
Log ε_6, µ.strains	2,06	2,12	2,16	2,12	2,08
Slope of the fatigue line	-5,293	-6,935	-8,956	-5,322	-4,718
$E^*_{initial}$, MPa	13832	10631	10992	12591	14268
Void content, %	9,6	9,8	9,8	8,9	9,3

Aggregate internal structure

Digital image analysis was used to investigate the aggregate internal structure. With the help of the iPas software which uses common digital image processing techniques to convert colored images of asphalt mixtures into black and white binary images, the internal structure was analyzed in terms of contact points and contact length. Contact point is defined as the stage where the pixels representing two adjacent aggregates are closer than a predetermined distance which is selected to be 0.1 mm in this study. Figure 4 depicts an example of how the contact points and total contact length is determined.

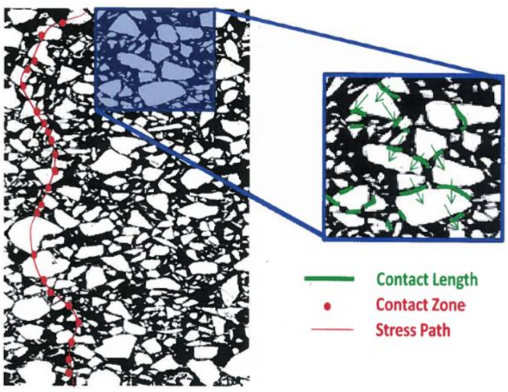

Figure 4. Digital Image and method of determining the contact length [7].

Contact length between two aggregates corresponds to the summation of the pixels' length in the contact zone that are within the distance of 0,1 mm. The quality of the internal aggregate structure of a mixture can be quantified by means of the number of contact points and contact (proximity) length normalized to a unit area; The higher these values are, the better the aggregate structure of the mixture in terms of ability to better perform (deform less) under thermal and mechanical loadings. As shown in Table 9, mixtures containing the "plastomer" have higher number of contact points and contact length than the SBS mixes. Low molecular weight polyolefins have low viscosities above their melting point. As a result, they can act as processing aids for better aggregate mobility during compaction and therefore improve the aggregate internal structure when compared with other mixtures. This effect has been obtained with or without combination of SBS.

Table 9: iPas test results

Mixture	Number of contact points		Total contact length	
	Average	STDEV	Average	STDEV
50/70+3%SBS	**5825**	230	**3258**	138
50/70 +2%SBS +0.8% Plastomer	**9589**	222	**4998**	140
50/70 +3% Plastomer	**6493**	119	**3671**	189

Previous studies showed that mixtures with more contact points and/or contact length exhibit better performance in terms of rutting, thermal and fatigue cracking and therefore a mixture with better aggregate packing is more favorable [7, 8, 4]. Figure 5 confirms the correlation with wheel tracking results (R^2=0.88) where mixtures with better aggregate packing were shown to have higher resistance to permanent deformation.

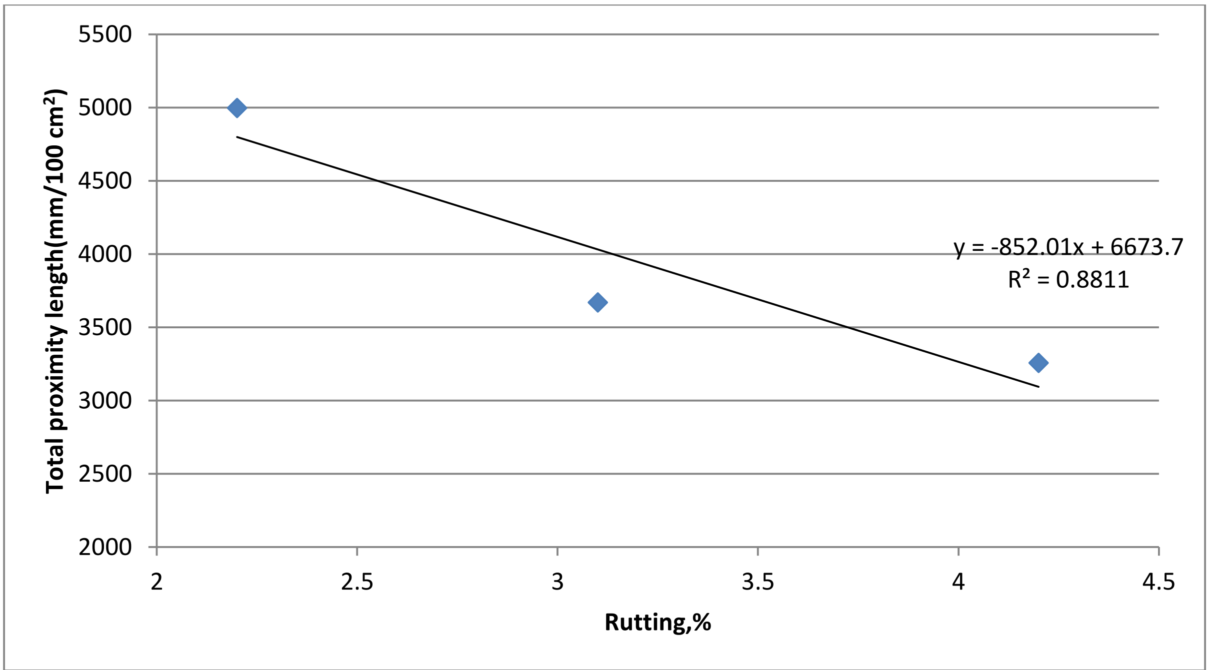

Figure 5: Correlation between rutting and total proximity length

CONCLUSIONS

The presented paper reports the results from an asphalt mixture study of the effect of two asphalt modifiers on laboratory simulated mixtures performance. Asphalt mixtures modified with an elastomer, a plastomer, and a combination of both types of polymer were compared with unmodified formulations. The main properties described in the European norm EN 13108-1 for Asphalt Concrete were generated. From this study, the following findings can be stated:

- The studied plastomeric additive is a low molecular weight polyolefin that becomes fluid above its melting point. It improves the workability of the mixture. As a result, the plastomer modified mixture can be processed at lower temperature than the elastomer modified mixtures.
- The considered additives (both plastomers and elastomers) improve the engineering characteristics of asphalt mixtures, which is expected to provide better performance of pavements.
- The EN 13108-1 specifications for an AC 10 SURF can be met with asphalt concrete modified by a plastomer, or modified by a plastomer and an elastomer (the so-called hybrid formulation). Therefore the benefits of easier handling and compaction can be realized without the risk of losing the benefits known for polymer modification.
- Lower air voids were obtained in the Gyratory Compactor when the plastomer was used in the formulation as single polymer or in Hybrid formulation.
- The use of functionalized plastomers decreases the moisture sensitivity as observed in boiling and ITSR tests. It also increases both the stiffness (indirect tension), the strength (Duriez method) and the rutting resistance (large device, wheel tracking test). In all cases, the best performance is obtained with hybrid formulations.
- Aggregate structure seemed to be an important factor in governing the performance of asphalt mixtures. Proper binder modification (in this case hybrid formulations) provides better aggregate mobility during mixture compaction stage, resulting in asphalt mixtures specimens that have higher aggregate structure indices (number of contact points and contact length measured by imaging analyses software iPAS2).

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- Image analysis: University of Wisconsin (USA)

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