Asphalt for heavily loaded pavements

Marjan Tušar[1, 2, a]

National Institute of Chemistry, Ljubljana, Slovenia
Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia

marjan.tusar@ki.si

Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.103

ABSTRACT

On the surface of asphalt pavements two types of damages are most common, namely the cracking and rutting. Surface cracking, which initiate at the surface of the wearing layer of asphalt, occurs most frequently, because a binder at low temperatures becomes too fragile. Rutting occurs at elevated summer temperatures, due to low viscosity of binder insufficient to sustain high traffic loads. As the binder in the asphalt layers mostly paving grade bitumen is used, which has a relatively small temperature range between too low and too high viscosity to withstand heavy loads. To increase the temperature range of bitumen in the bitumen various so-called modifiers are added. Most often SBS (styrene-butadiene-styrene block copolymer) is used to modify bituminous binder for higher traffic roads. SBS increases quality of asphalt, but it has many drawbacks; modifier is expensive, producer have to increase temperature when producing SBS modified asphalt mixtures and laying of asphalt course with SBS modified bitumen is more difficult than with paving grade bitumen.

In this study, we found that the addition of Poly-methyl methacrylate/aluminium trihydrate (PMMA/ATH) composite in the asphalt mixture increases the resistance of asphalt layers to permanent deformations and increases durability of asphalt. With laboratory trials we managed to reduce proportional rut depth by a factor of three, when PMMA/ATH composite was added to bitumen. The highest degree of resistance to the formation of ruts, which was five fold lower than in the reference asphalt layer was achieved by adding a combination of PMMA/ATH composite powder and paraffin waxes in the bitumen.

Already in 2009 test fields were built. First dry process of adding PMMA/ATH composite to asphalt mixture was applied and in 2013 wet process of adding PMMA/ATH composite to bitumen was utilized. Produced asphalt was successfully built in test fields and regular roads.

In comparison to SBS we found some advantages of adding PMMA/ATH in the asphalt: cheaper additive, easier production of modified binder, there is no need for an elevated temperature at asphalt production, asphalt did not stick to shovels and it was found out that workability of asphalt is even improved.

Keywords: Additives, Adhesion, Industrial application, Permanent Deformation, Polymers

1. INTRODUCTION

Asphalt is the most widely used material for road surfaces. Two types of deterioration processes, namely the cracking and rutting, are the most common on asphalt surfaces. Quality of binder predominately effects the formation of cracks and on rutting on the asphalt pavements. Surface cracks occur most frequently, because the binder becomes stiffer at lower temperatures. Rutting is produced at elevated summer temperatures because viscosity of binder becomes too low to sustain high traffic loads. Ordinary paving grade bitumen has a relatively small so called plasticity temperature range. This means that high possibility exists that deterioration processes will occur in asphalt pavements containing paving grade bitumen during its lifetime. To increase the plasticity range of bitumen various so-called modifiers are added. Most often SBS (styrene-butadiene-styrene block copolymer) modified bitumen binders are used on roads with heavy traffic loads. There are several problems caused with such modification: SBS is expensive, the process of preparing SBS-modified bitumen is demanding and laying asphalt layer containing SBS-modified bitumen is more difficult compared to laying asphalt layer containing paving grade bitumen.

In the scope of the national research project, we developed a new modifier for bitumen, which increases the durability of asphalt. Poly-methyl methacrylate filled with a fine dispersion aluminium trihydrate (PMMA/ATH) is added to bitumen to increase the sustainability of asphalt layers and their resistance to formation of ruts.

2. INPUT MATERIAL AND EXPERIMENTAL WORK IN LABORATORY

PMMA/ATH composite plates are used mainly as desks and counters. Due to high hardness, resistance to most chemical substances, mechanical and volume stability at low and high temperatures of such plates, they can be used also outdoor. Round 60 wt. % of the dust is Aluminium trihydrate (Al $(OH)_3$) which is chemically similar to Hydrated lime (Ca $(OH)_2$). Chemically they are both metal hydroxides. It is known that hydroxide is a diatomic anion with chemical formula OH^-. It consists of an oxygen and hydrogen atom held together by a covalent bond, and carries a negative electric charge. It functions as a base, a ligand, a nucleophile and a catalyst. The hydroxide ion forms salts. Hydrated lime is known as additive to improve adhesion in asphalt mixtures, particularly for siliceous aggregates. It improves resistance to water in two major ways. First on the surface of aggregates it improves compatibility between the binder and aggregate [1]. Second, lime reacts with acid components of the asphalt binder to create insoluble calcium salts that are hydrophobic. The elimination of the acid components in the binder promotes the formation of strong nitrogen bonds between the bitumen and the aggregate [2].

PMMA/ATH composite dust is the waste material obtained by polishing of PMMA/ATH composite sheets. Final goal of our study was new asphalt mixture containing the PMMA/ATH composite dust.

There are two ways to introduce PMMA/ATH dust as additive in asphalt mixture. First it was treated as additive to filler in asphalt mixtures (dry process) and second PMMA/ATH dust was treated as additive to bitumen (wet process). After first tests it was clear that the addition of dust even improves the quality of the asphalt layers. For dry process we had to determine the optimal ratio between ordinary filler and PMMA/ATH dust to achieved good mechanical properties of asphalt layer. Also for wet process optimal ratio between bitumen and PMMA/ATH dust had to be determined. We tried to find out, if the bitumen modified with PMMA/ATH dust has similar properties as bitumen modified with other commercial additives.

Several different asphalt mixtures containing PMMA/ATH dust were prepared in laboratory and several standard test methods were performed to evaluate asphalt mixtures (EN 12697-1, 2, 5, 6, 22, 30, 34, and 46).

First adhesion of bitumen on PMMA/ATH was tested. From PMMA/ATH plate aggregate with grain size 5/8 mm was prepared and tested according to adhesion test (EN 12697-11). In figure 1 PMMA/ATH grains before and after adhesion test are presented. After test grains were 100% covered with bitumen.

Figure 1: PMMA/ATH grains before and after adhesion test are presented.

For 3 different types of asphalt mixtures industrial production was carried out, which means that we produced around 740 tons of asphalt mixtures, and laid them in a field test (normal road) [3].
To address the human health and environment we assessed the risk for chemicals. We performed quantitative and qualitative analysis of dust and vapour, which are exhausted by heating of PMMA/ATH dust up to 180^{o}C.
For asphalt mixtures prepared in laboratory paving grade bitumen B 70/100 and dolomite stone aggregate were used.

2.1 PMMA/ATH composite dust as additive to filler (dry process)

First standard tests were performed to enable the addition of PMMA/ATH composite dust as filler in asphalt mixture [4]. It was proved that adhesion between PMMA/ATH composite and bitumen is as good as expected. We had to assure that sieving curve (Tab. 1) and void content with Rigden test (Tab. 2) were in accordance with standardized requirements.

Table 1: Sieving analyses according to method EN 933-10:2002 of ordinary filler, PMMA/ATH composite dust and their mixtures in weight percent

Sieve (mm)	PMMA/ATH composite dust	Ordinary filler	Ordinary filler : PMMA/ATH composite dust = 5:1 wt.	Ordinary filler : PMMA/ATH composite dust = 8:1 wt.	Requirement according to EN 13043
2.00	100 %	100 %	100%	100%	100%
0.125	*74 %*	98 %	94%	95%	85% – 100%
0.063	*41 %*	89 %	81%	84%	70% - 100%

Table 2: Voids according to method EN 1097-4:2008 of dry compacted ordinary filler, PMMA/ATH composite dust and their mixtures

PMMA/ATH composite dust	Ordinary filler	Ordinary filler : PMMA/ATH composite dust = 5:1 wt.	Ordinary filler : PMMA/ATH composite dust = 8:1 wt.	Requirement according to SIST 1038-1
53 %	34 %	37 %	36 %	28%- 38%

We determined that weight ratio 5:1 between ordinary filler and PMMA/ATH composite dust is still in accordance with standardized requirements for filler.

2.2 PMMA/ATH composite dust as additive to bitumen (wet process)

Silverson L5M homogenizer was used for mixing different quantities of PMMA/ATH composite dust in paving grade bitumen B 70/100 [5, 6, 7]. To ensure a good dispersion dust was mixed in bitumen for 1.5 h at 170 ºC. Additionally we prepared sample containing 3 wt. % of paraffin wax (Sasobit) and 25 wt. % of waste PMMA/ATH. Several test methods were used to evaluate quality of produced modified bitumen such as needle penetration at 25 ºC, softening point, Fraass breaking point and rut resistance potential (G*/sin(δ)) (Tab. 3). With RTFOT ageing procedure also short term (Tab. 4) and with PAV procedure long term (Tab. 5) ageing potential of modified bitumen were evaluated.

Table 3: Properties of PMMA/ATH composite dust modified bitumen [5]

PMMA/ATH composite dust content in bitumen (wt. %)	Softening point (ºC)	Fraass breaking point (ºC)	Penetration at 25 ºC, (0.1 mm)	G*/sin(δ) (kPa at 50 ºC)
0	46.2	-11	78	3860
25	53.6	-15	55	10890
0 (3% wax)	71.0	-13	54	
25 (3%wax)	93.8	-12	34	

With simple test methods such as needle penetration at 25 ºC, softening point and Fraass breaking point only insignificant differences between base bitumen and bitumen modified with PMMA/ATH composite dust were determined (Tab. 3). Only addition of paraffin wax significantly affected softening point. But both additives together seem to have multiplicative effect on softening point of bitumen.

From G*/sin(δ) measurements with dynamic shear rheometer we found significant differences between asphalts containing base bitumen and asphalts containing bitumen modified with PMMA/ATH composite dust. From these results increased resistance to permanent deformations was expected.

Table 4: Properties of RTFOT aged bitumen [5]

PMMA/ATH composite dust content in bitumen (wt. %)	Softening point (ºC)	Fraass breaking point (ºC)	Penetration at 25 ºC, (0.1 mm)	G*/sin(δ) (kPa at 50 ºC)
0	54.2	-11	40	14022
25	61.8	-13	26	38700
25 (3%wax)	92.0	-9	22	

With RTFOT ageing procedure as expected all properties of bitumen changed (Tab. 4).

Table 5: Properties of RTFOT and PAV aged bitumen [5]

PMMA/ATH composite dust content in bitumen (wt. %)	Softening point (ºC)	Fraass breaking point (ºC)	Penetration at 25 ºC, (0.1 mm)	G*/sin(δ) (kPa at 50 ºC)
0	66.6 (+44%)	-2	21 (-73%)	79428
25	74.2 (+38%)	-7	17 (-69%)	170945
25 (3%wax)	93.6 (-0.2%)	-7	21 (-38%)	

With RTFOT and PAV ageing procedure it can be seen that the significant changes of properties were measured at unmodified bitumen. The minimum change in properties was found when combination of PMMA/ATH and paraffin wax was used (Tab. 5).

2.3 Asphalt mixtures containing PMMA/ATH composite dust

For laboratory testing four AC 8 asphalt mixtures were prepared. First mixture contained PMMA/ATH composite dust as additive to filler in mass ratio 1:5 [4] (PMMA/ATH: filler), second contained PMMA/ATH composite dust in paving grade bitumen B 70/100 in mass ratio 1:3 (PMMA/ATH: bitumen), third was similar to second with additionally 3 wt. % paraffin wax and fourth reference was without PMMA/ATH composite dust [6, 7].

For all asphalt mixtures wheel tracking parameters (according to EN 12697-22 with small device) and water sensitivity (according to EN 12697-12) were determined. Wheel tracking tests were performed at 50 °C. Proportional rut depth of mixture containing PMMA/ATH composite dust in paving grade bitumen B 70/100 is approximately 3 times lower in comparison to the reference mixture (Fig. 2). The results of wheel tracking test are in good agreement with G*/sin(δ) values determined with binder test.

Increased water resistance of samples containing PMMA/ATH composite dust (ITS ratio) implies that waste PMMA/ATH particles in asphalt binder improve the adhesion performance between aggregate and bitumen (Tab. 6). From result it can be seen that more effective is addition of PMMA/ATH in bitumen.

Table 6: Properties of PMMA/ATH composite dust modified asphalt [7]

Samples of AC 8 surf	ITS at 25 °C (kPa)	ITS ratio at 25 °C (%)	Proportional rut depth at 50 °C (%)	WTS_{AIR} at 50 °C (μm/cycle)
Reference mixture	907	93.1	18.3	0.46
PMMA/ATH composite dust added in filler	895	94.4	9.0	0.16
PMMA/ATH composite dust added in bitumen	1102	99.2	6.3	0.09
PMMA/ATH composite dust added in bitumen + 3% wax	1215	97.5	3.5	0.03

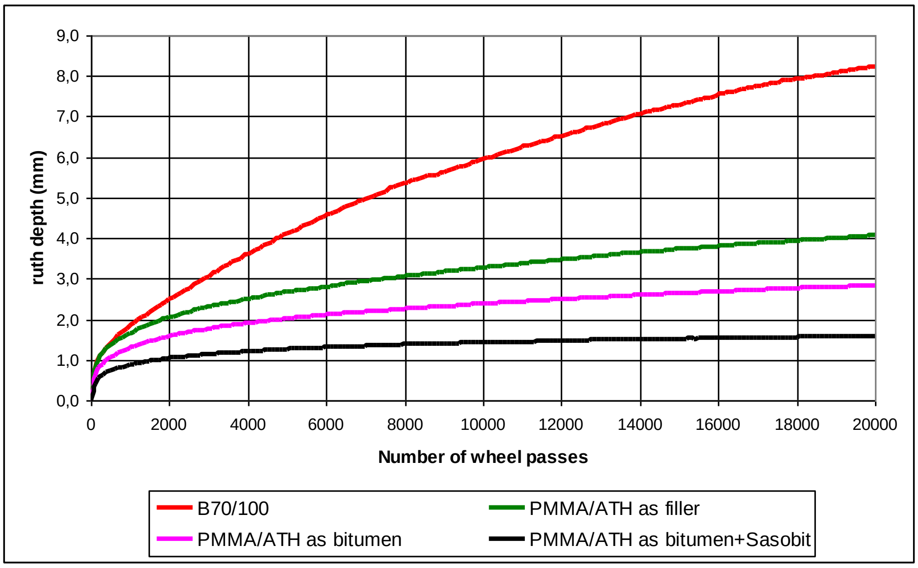

Figure 2: Results of wheel tracking test at 50 °C

For all asphalt mixtures compactability (according to EN 12697-10) and low temperature properties (according to EN 12697-46) were determined (Tab. 7). Samples with PMMA/ATH composite dust added in filler give similar or even better results than reference mixture at these two tests. From compactability test it was assumed that compaction of asphalt layer will be harder, when PMMA/ATH composite dust is added in bitumen. In table 7 are results of thermal stress restrained specimen test (TSRST) and tension strength reserve ($\Delta\beta_t$(T)).

Table 7: Properties of PMMA/ATH composite dust modified asphalt [7]

Samples of AC 8 surf	Compactability at 160 °C	TSRST failure temperature (°C)	TSRST failure stress σ cry (MPa)	Tensile strength reserve T Δβ, max. (°C)	Tensile strength reserve, Δβ, max. (MPa)
Reference mixture	26.4	-24.7	4.0	-8.4	3.8
PMMA/ATH composite dust added in filler	26.5	-28.1	4.4	-10.0	4.3
PMMA/ATH composite dust added in bitumen	30.4	-26.3	4.5	-6.3	4.4
PMMA/ATH composite dust added in bitumen + 3% wax	31.5	-22.7	5.1	-5.5	4.5

3. FIELD EXPERIENCES

In 2009 we produced 120 tons of asphalt containing PMMA/ATH composite dust in filler and for comparison the same amount of ordinary asphalt. At construction of the test section with PMMA/ATH composite dust in binder course, workers noticed that it was easier to handle with asphalt containing PMMA/ATH composite. The driver of asphalt paver confirmed that workability of asphalt is improved, when it is containing PMMA/ATH composite dust. The test field with PMMA/ATH composite dust in wearing course is still monitored and there are no visible defects on the surface (fig 3). After first two field trials more than 1000 tons of asphalt containing PMMA/ATH composite dust in filler was produced for commercial use.

a. b.

Figure 3: Construction of test field with PMMA/ATH composite dust in wearing course in 2009 (a.) and the same test field in 2013 (b).

Test field with PMMA/ATH composite dust added in bitumen was built in 2013. We produced 500 tons of asphalt containing PMMA/ATH composite dust. The production of bitumen containing PMMA/ATH composite dust was carried out in bitumen tank with mixer (fig. 4). Modified bitumen was used in 24 hours after mixing. We did not notice any problem when asphalt containing modified bitumen was produced. At construction of the test section with PMMA/ATH composite dust in binder course, workers did not notice any difference in comparison to reference asphalt.

Figure 4: Production of bitumen containing PMMA/ATH composite dust.

4. CONCLUSIONS

From test result performed on bitumen it can be seen that addition of PMMA/ATH composite dust always improved quality of bitumen. From rheological results increased resistance to permanent deformations was expected.

From laboratory tests performed on asphalt we concluded that addition of PMMA/ATH composite dust always improves quality of asphalt. Increased water resistance of samples containing PMMA/ATH composite dust (ITS ratio) implies that waste PMMA/ATH particles in asphalt binder improve the adhesion performance between aggregate and bitumen. Also resistance to permanent deformations increased. In our opinion the reason for improved properties of asphalt is in increased adhesion between bitumen and stone aggregates. From test result it can be seen that more effective is addition of PMMA/ATH in bitumen. As already known addition of paraffin wax (containing from 40 to 110 carbon atoms in the alkane chain) in asphalt improves resistance to permanent deformation. With our study we found out that both additives together seem to have multiplicative effect on resistance to permanent deformation.

With test production and test fields we proved that addition of PMMA/ATH composite dust can be applied in normal batch type asphalt plant. On asphalt plant CGP in Drnovo we performed both dry and wet process. Test field from 2009 is a proof that PMMA/ATH modified asphalt is at least equally durable as ordinary asphalt. Due to the fact that PMMA/ATH was industrial waste and it improves the quality of asphalt pavement we can proclaim that PMMA/ATH modified asphalt is sustainable solution.

ACKNOWLEDGEMENTS

I would like to thank Mrs. Zupančič-Valant and Mrs. Šušteršič for performing rheological testing.

I would like to thank Mrs. Bohinc, Mr. Ipavec and Mr. Kmet from ZAG for performing extensive bitumen and asphalt testing.

I would like to thank Tomislav Šafran, Matija Šafran and Iztok Ramljak from Ramtech for performing low temperature asphalt testing.

REFERENCES

[1] Kennedy, T. W. and Ping, W. V.: Evaluation of Effectiveness of Antistripping Additives in Protecting Asphalt Mixtures from Moisture Damage, Journal of the Association of Asphalt Paving Technologists, from the Proceedings of Technical Sessions, 1991.

[2] Little, D.N. and Petersen, J. C., “Unique Effects of Hydrated Lime Filler on the Performance-Related Properties of Asphalt Cements: Physical and Chemical Interactions Revisited,” Journal of Materials in Civil Engineering, March/April 2005.

[3] Tušar M., Šušteršič E., Zupančič-Valant A., Alternative PMB produced from recycling waste PMMA/ATH = Alternatywne PMB produkowane z odpadów recyklingowych PMMA/ATH. Transport problems, ISSN 1896-0596. [Printed ed.], 2014, vol. 9, iss. 2, str. 5-9.

[4] Tušar M., Beličič A., Prešeren M., Asfalt z dodanim PMMA/ATH (Asphalt with added PMMA/ATH) Patent in Slovenia: SI23670 (A), 2012-09-28. Ljubljana: Urad Republike Slovenije za intelektualno lastnino (The Slovenian Intellectual Property Office), 2012.

[5] Šušteršič E., Tušar M., Zupančič-Valant A. Effective concept of asphalt concrete modification with waste PMMA/ATH. Materials and Structures, 2014, Volume: 47 Issue: 11 Pages: 1817-1824.

[6] Tušar M., Beličič A., Prešeren M., Šušteršič E., Novič M., Zupančič-Valant A., S PMMA/ATH kompozitnim prahom modificiran bitumen in uporaba le-tega (Bitumen modified with PMMA/ATH composite dust and its use) : Patent application in Slovenia: P-201200213, 2012-06-20. Ljubljana: Urad Republike Slovenije za intelektualno lastnino, (The Slovenian Intellectual Property Office) 2012.

[7] Šušteršič E., Tušar M., Zupančič-Valant A. Rheological and mechanical characterization of waste PMMA/ATH modified bitumen. Constr. build. mater., 2013, vol. 38, pages 119-125.