PREDICTING THE DURABILITY OF WARM MIX ASPHALT

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ABSTRACT:

Hot Mix Asphalt (HMA) has been the world's main type of paving material. In the last 10 to 15 years the asphalt industry has recognised the importance of sustainability and the need for new innovative materials. The introduction of warm mix asphalt (WMA) technologies allow asphalt production and compaction temperatures to be reduced. However the issue of their longer term durability has been unknown. This investigation considered the development of a new approach to predicting the durability of WMA based on simulated trafficking and 3D modelling. Roller compacted SMA14 test specimens were prepared using 4 WMA additives and compared with a WMA control containing no additive and a conventional HMA. The test specimens were subjected to simulated accelerated trafficking using modified Wessex immersion wheel track test equipment. This had been fitted with a pneumatic tyre and modified so the tyre is dragged across the test specimen in one direction. This causes the surface to eventually ravel and breakup. 3D models of the test specimen before and after simulated trafficking were made using a hand held ZScanner 800 3D laser. Changes in the 3D models were analysed using DigitalSurf MountainsMap6 Premium software. In developing this test method it was found that test temperature and compaction were important factors in causing the asphalt mix surface to ravel. After testing at 30^{0}C it was concluded that addition of the 4 additives used did not detrimentally affect the durability of WMA SMA14 asphalt mixes in comparison to the HMA control. Based on the findings of this test method it is concluded that if properly compacted, the use of additives will result in warm mix SMA that is comparable to hot mix SMA in terms of aspects of durability assessed.

KEY WORDS: Warm Mix Asphalt, Hot Mix Asphalt, Durability, 3D modelling.

INTRODUCTION

This paper describes the use of a durability test method called the Dragged Ravelling Test (DRT) that uses 3D modelling to quantify change in the test specimen as a result of testing. Durability is now an increasingly important asphalt mix property and is central to the generic ideals of sustainability. The 1st July 2013 saw full implementation of the Construction Products Regulation (CPR) in the member countries of the European Economic Area. One of the 35 product areas listed in the CPR is road construction products. The CPR aims to breakdown technical barriers to trade and has four main elements i.e. a system of harmonised technical specifications, an agreed system of conformity assessment for each product family, a framework of notified bodies and CE marking of products. CE marking implies a product that is consistent to its Declaration of Performance (DoP). It harmonises the methods of assessment and test.

Seven basic generic requirements are stated for the named product areas: (i) mechanical resistance and stability (ii) safety in case of fire (iii) hygiene, health and the environment (iv) safety and accessibility in use (v) protection against noise (vi) energy economy and heat retention and (vii) sustainable use of natural resources. Within the context of asphalt mixes this generic listing of requirements is open to interpretation. As a result of the CPR, European specification EN 13108 for harmonised asphalt products such as asphalt concrete, hot rolled asphalt, stone mastic asphalt and porous asphalt are currently being revised to be made compliant with the CPR.

This paper summarises a new durability test that uses 3D modelling techniques to quantify change of the test specimen. The reason for development of a specific durability test was the findings of a review of the existing harmonised European asphalt test methods. This had found that of the approximately 50 test methods available in EN 12697 there was no specific test for assessing durability. It was felt that the seven basic generic requirements of the CPR pose significant challenges if reliance is placed on current harmonised European Standards to predict the longer term durability performance of asphalt surfacing materials.

CE Marking and a Declaration of Performance imply knowledge of how the product will perform in-service, from initial design to its eventual reuse as a recycled construction material. Surrogate methods such as retained stiffness of conditioned test specimens have been used for many years in Ireland the UK to get some idea of in-service performance.

It was felt that there was a need for a new method to better predict asphalt durability. As many different factors affect the durability of an asphalt mix, the new test was designed to be readily adaptable to be able to assess differing in-service factors such as compaction, temperature and the presence of moisture. It had to meet the following ideal conditions:

- Simulate tyre / asphalt interaction.
- Be able to vary test conditions to simulate differing in-service conditions.
- Assess the asphalt mix and / or highlight the role / function of specific components in the mix.
- Pre-test conditioning of test specimens to assess effect of climatic conditions.
- Result is a comparative ranking that agrees with expected in-service performance.

This set of ideal conditions posed a problem as many of the existing harmonised European test equipment's are quite complex and insufficiently adaptable. With regard to simulating in-service conditions almost none involve tyre / asphalt interaction. After a number of unsuccessful attempts the resulting DRT test described in this paper is based on the Immersion Wheel Track Test originally developed by the UK Road Research Laboratory in the 1950s [1]. A line drawing of the original equipment is shown in Figure 1.

In the original method a bituminous test specimen was immersed in water at 40^0C for 1 hour. A loaded hard rubber tyre moved back and forth across its surface. The combination of soaking in water at an elevated temperature and wheel tracking induced rutting of the test specimen. Test duration could be increased to determine when stripping of the bitumen / aggregate bond occurred leading to cohesive failure of the test specimen. The Immersion Wheel Track Test was subsequently modified in 1987 with a one way braking system to increase contact stress during testing with the solid rubber tyre replaced with a steel tyre [2].

In this latest version of the test method, the solid rubber tyre has been replaced with a treaded pneumatic tyre to better simulate rubber contact with the textured surface of an asphalt test specimen. The one way braking system has been retained to increase contact stress and so exploit any weakness or issue that could result in premature durability related failure. What makes this latest version of a 60 year old test method innovative is the use of 3D modelling to quantify change in the test specimen surface as a result of simulated trafficking.

This paper summarises the main parts of the test method giving examples of its adaptability. It then summarises a case study based on a warm 14mm Stone Mastic Asphalt (SMA14) made with four different warm mix additives that uses the method to get an idea of their durability compared to a conventional hot mix SMA14 [3].

DEVELOPMENT OF THE DRAGGED RAVELLING TEST

The Dragged Ravelling Test (DRT) was developed as part of research programme into the durability of warm mix asphalt sponsored by the Irish National Roads Authority Research Fellowship Programme [3, 4]. The objective of the test method development was to simulate conditions at the tyre / asphalt mix interface and allow prediction of durability. The test equipment offers the ability to accelerate a range of failure mechanisms that may be experienced at this interface.

These range from the consequences of poor compaction, ravelling of surface aggregate, secondary compaction and moisture sensitivity to loss of adhesion / cohesion. Being able to quantify this diverse range of failure mechanisms could have proven quite difficult. However, 3D modelling has been used to easily quantify any change in the tyre / asphalt mix interface of the test specimen as a result of the test conditions

The DRT test method typically assesses roller compacted asphalt mix test specimens 305 x 305 x 50 mm in size. It can also use 150 mm diameter gyratory compacted test specimens or similar sized cores extracted from a compacted pavement. The method was specifically designed to be simple and readily adaptable. Factors such as test specimen compaction, test duration, type of test specimen pre-conditioning and water test temperature can be altered depending on what aspect of durability is being considered.

After making the asphalt mix test specimen the first stage of the DRT test involves securely fitting the test specimen in a rigid aluminium reference mould. The test specimen is kept in this reference mould throughout testing. The purpose of the reference mould is to provide a reference plane allowing accurate orientation and positioning of pre and post-test 3D models of the test specimen.

In this paper a hand held ZScanner800^{TM} High Resolution 3D Scanner was used to create 3D model point clouds of the asphalt mix test specimen. Stereo-photogrammetry may also be used with proprietary software used to create the 3D point cloud models. A pre-test 3D model of the asphalt mix test specimen is made first.

Figure 2 shows the asphalt mix test specimen in the reference mould with a mesh of control dots required for laser scanning. This was found to be the best method of capturing the surface detail using the hand-held 3D laser scanner. Control dots stuck to the surface of the asphalt mix test specimen did not result in as a good recovery of the surface being scanned.

The asphalt mix test specimen held securely in the reference mould is then placed in the modified wheel tracking equipment. In this paper a commonly available Mojo 10 x 4.5/5 go-cart tyre was used. Rain tyres were chosen over slicks to provide a tread pattern that was assumed to better interact with the textured surface of the asphalt mix test specimen. The effect of tyre inflation pressure and load on the contact patch of this pneumatic test tyre was assessed using a high resolution XSensor IX500.256.256.22 pressure mapping system. Figure 3 shows the pneumatic test tyre resting on the pressure pad.

The pressure pad has a 1.15mm spatial resolution and 65,536 sensing elements mounted on a rigid plexi-glass backing. It has a pressure measuring range of 10-200 psi with a data acquisition rate of 6.2 frames per second. XSENSOR X3 PRO Version 6.0 software records and displays data from the sensor pad. Data can be displayed in 2D or 3D. When data recording is complete it can be replayed and viewed as a continuous model or as individual frames. The data may also be exported into Excel, CAD or spatial GIS modelling software for further analysis.

The variation in contact patch area and stress distribution was assessed at test tyre inflation pressures ranging from 0 to 56 psi for three static loading conditions of 9.59 kg (condition A), 18.86 kg (condition B) and 28.06 kg (condition C). Figure 4 shows the contact patch change for loading condition C with a tyre inflation pressure of 18.5 psi. This complex distribution of stress within the contact patch is typical of any standard treaded tyre.

Figure 5 plots contact area for the 3 static loading conditions at different tyre inflation pressures. This plot is typical of most pneumatic tyres and shows contact area to increase as tyre inflation pressure decreases and to increase with load. For the purposes of the DRT testing reported in this paper static loading condition C was used with a test tyre inflation pressure of 20 psi.

During testing the pneumatic test tyre moves freely forward before becoming locked and dragged backwards across the asphalt mix test specimen. Again, the braking mechanism was designed to be as simple as possible giving 100 % braking / dragging effect. The test tyre and braking mechanism is shown in Figure 6.

After testing a post-test 3D model of the asphalt mix test specimen is made. Both 3D models are cleaned using the ZScanner ZScan software. The aluminium reference mould was found to be essential to accurately align the 3D models of the asphalt mix test specimen before and after testing. An example of a cleaned 3D model is sown in Figure 7. This clearly shows the reference mould used to orientate and position the 3D models. For the purposes of this paper the 3D point cloud data was then imported into Digital Surf MountainsMap6 software for areal surface texture analysis in accordance with BS EN ISO 25178-2 [5].

In the development of the test method to assess its adaptability, a range of differing conditions were considered. For example, could the method differentiate between test specimens with different levels of compaction. Figures 8 and 9 show 3D models of two SMA10 test specimens with bulk densities of 1848 kgm^3 and 2503 kgm^3 respectively. The test specimens were tested in water at 45^{0}C for 45 minutes.

These models are typical of what is produced using the MountainsMap6 software. Colour is used to emphasise the z-scale. The 3D models show that the less well compacted test specimen suffered much more material loss during these conditions. These models were created during development of the method before it was discovered that the reference mould was necessary. These models show the z-scales to be different.

Figure 10 and 11 show example 3D models for a poorly compacted test specimen before and after testing using the reference mould. In this example, the dragged test tyre has caused the poorly compacted asphalt mix test specimen to suffer considerable material loss. Initial analysis of the 3D model considered the entire test specimen.

To simply the analysis procedure, this was reduced to just that part of the asphalt mix test specimen that was subjected to simulated trafficking. This is termed an Area of Interest (AOI). Figure 12 shows an example AOI selected for analysis. In this example the dimensions of the AOI were 155 x 200 mm in size. However, once the 3D model is created, any part of the entire 3D model can be analysed using the MountainsMap6 software.

CASE STUDY - USE OF DRT TO ASSESS THE DURABILITY OF WARM 14MM STONE MASTIC ASPHALT

The following case study shows how the DRT test can be used to assess the durability of warm mix 14mm Stone Mastic Asphalt (SMA14). The aggregate used to make the asphalt mixes was a Silurian greywacke mixed with unmodified 70/100 penetration grade and 0.3% cellulose fibres. Table 1 summarises the SMA14 mix design. Table 2 summarises the 4 warm mix additives used in this study i.e. 2 chemical, 1 foaming and 1 organic. The following mixtures were assessed:

- standard hot mix SMA14 (HMA)
- warm mix SMA14 with no additive (WMA N)
- warm mix SMA14 with additive Product A (WMA PA)
- warm mix SMA14 with additive Product B (WMA PB
- warm mix SMA14 with additive Product C (WMA PC)
- warm mix SMA14 with additive Product D (WMA PD)

SMA14 test specimens were compacted using a Copper roller compactor. The mixing temperature of the standard hot mix SMA14 was 160^0C. The mixing temperature was reduced by 30^0C from 160^0C to 130^0C for all the warm SMA14 test specimens. Table 1 details the bulk density of each test specimen showing all of the test specimens to have similar bulk density. This reflects the roller compacted method of compaction were the same mass of asphalt mix was used to prepare slabs all with dimensions 305 x 305 x 50 mm. In this case study, all the asphalt mix slab test specimens were preconditioned by soaking in water at 30^0C for 60 minutes. They were then DRT tested for 60 minutes with static load of 28 kg and tyre inflation pressure of 20 psi. 3D models were made before and after testing using the aluminium reference mould to orientate and locate the 3D models.

Analysis was carried out using MountainsMap6 software. The post-test variation in depth profile of the AOI was measured using a Step Height Measurement procedure. An example of how Step Height Measurement can be used to measure a rut depth is shown in Figure 13. This example shows that very small measurements of less than 1 mm are possible. Transverse profiles across the tracked profile were measured at 7 locations i.e. at positions P40, P80, P120, P160, P200, P240 and P280. Profile P40 was measured 40 mm from the top edge of the 3D model, P80 was measured 80 mm from the top edge of the 3D model.

The profile data measured at each of the 7 locations for each of the test specimens is summarised in Table 4. This also shows the average profile depth. The average profile depths are plotted in Figure 12. They are all less than 1 mm indicating the warm mix SMA14 mixtures to be of similar durability to the hot mix SMA14.

The SMA14 warm mix 3D models were assessed to determine difference in surface volume loss using the Volume of a Hole procedure in MountainsMap6. Figure 15 summarises the difference in volume for the test specimens as a result of testing. This compared the pre-test and post-test models to determine their difference in volume. The small amounts of material loss are similar.

This case study relating to well compacted hot and warm SMA 14 illustrates the small amounts of measurement achievable using this 3D model method of assessment. This is in contrast to the previous examples shown in this paper where much larger amounts of material loss resulted. Both the profile and the volume loss data show that the warm mix SMA14 test specimens have comparable performance to the hot mix SMA14 test specimen. This indicates that the reduction in temperature combined with the use of WMA additives does not have a negative effect on the durability of the SMA14 assessed in this case study.

CONCLUSION

This paper has summarised the development of a durability test method that has been developed to better predict the durability of asphalt surfacing mixtures. It is based on a 60 year method that simulates tyre / asphalt mix interaction with 3D modelling used to quantify any resulting change. Depending on the test conditions it is possible to induce different types of durability related failure mechanisms. The use of a reference mould to accurately place the scanned specimens for 3D analysis was found to be essential to allow accurate pre and post-test comparison. The SMA14 warm mix case study illustrated that they performed similar to the hot mix SMA14.

ACKNOWLEDGMENT

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Table 1. Mix design for SMA14

Sieve Size (mm)	Aggregate % passing	Aggregate Target % Passing	% Retained
20	100	100	0
14	90 - 100	100	0
10	35 - 60	47.5	52.5
6.3	20 - 45	32.5	15
2	15 - 30	22.5	10
0.25	-		
0.063	6 - 12	9	13.5
% Binder		5.3	
% Cellulose Fibres		0.3	

Table 2. WMA product details

Product descriptor	Abbreviation used in paper	Asphalt product	Type of additive	Recommended dosage rate
Hot Mix Asphalt	HMA	Hot Mix Asphalt	-	N/A
WMA with no additive	WMA N	Warm Mix Asphalt with no additive	-	N/A
Product A	WMA PA	CWM®	Chemical	0.4% of binder content
Product B	WMA PB	Long chain hydrocarbon wax	Organic	3% of binder content
Product C	WMA PC	Advera®WMA	Foaming	0.25% of bituminous mixtures
Product D	WMA PD	Rediset LQ	Chemical	0.5% of binder content

Table 3. Bulk density data for SMA14 test specimens.

Test Specimen	Bulk Density (kg/m^3)
HMA	2136
WMA N	2132
WMA PA	2125
WMA PB	2120
WMA PC	2134
WMA PD	2113

Table 4. Comparison of SMA14 profile depths.

	Profile depths (mm)					
Profile	HMA	WMA N	WMA PA	WMA PB	WMA PC	WMA PD
P40	0.29	0.29	0.23	0.26	0.62	0.50
P80	0.83	1.50	1.43	0.97	0.38	1.74
P120	0.83	0.5	0.57	0.03	0.74	0.93
P160	0.63	0.66	1.25	0.66	0.23	0.99
P200	0.56	0.38	0.29	0.23	0.22	1.37
P240	1.04	1.10	0.22	0.67	0.72	1.19
P280	0.53	0.63	0.64	0.21	0.69	1.24
Average	0.67	0.72	0.66	0.43	0.52	1.14

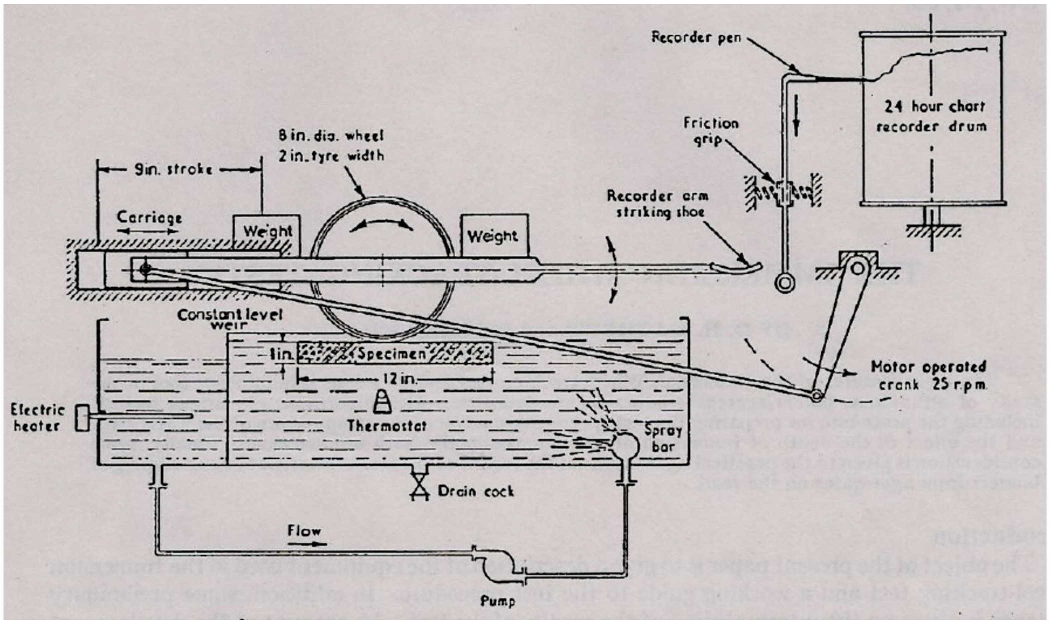


Figure 1. Line drawing of original immersion wheel tracking machine.

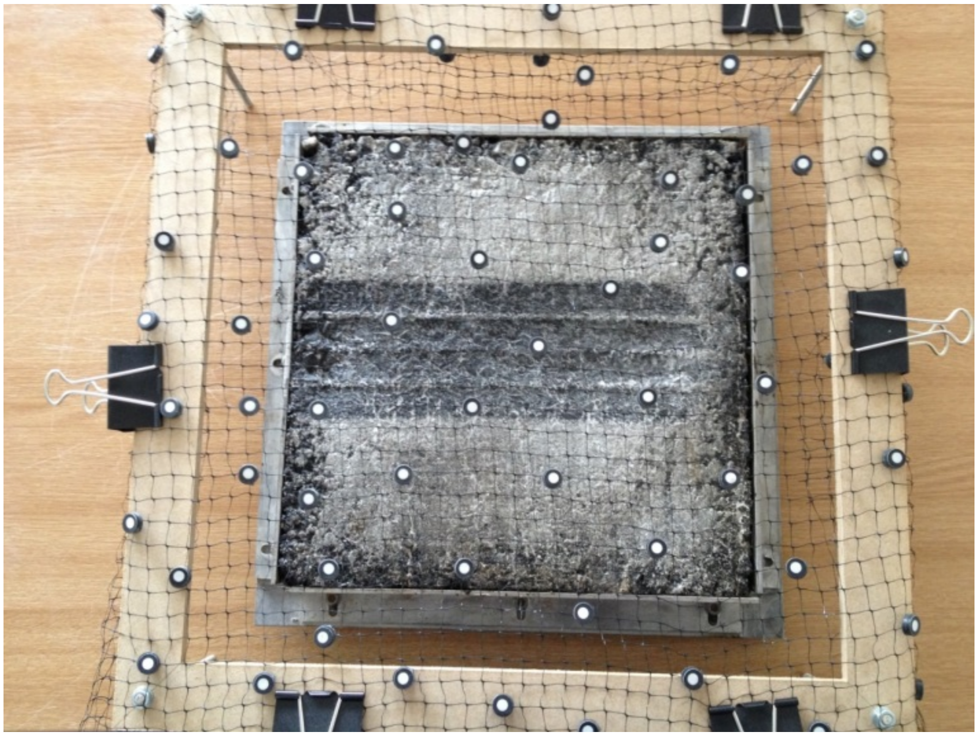


Figure 2. Asphalt mix test specimen in reference mould ready for 3D laser scanning.

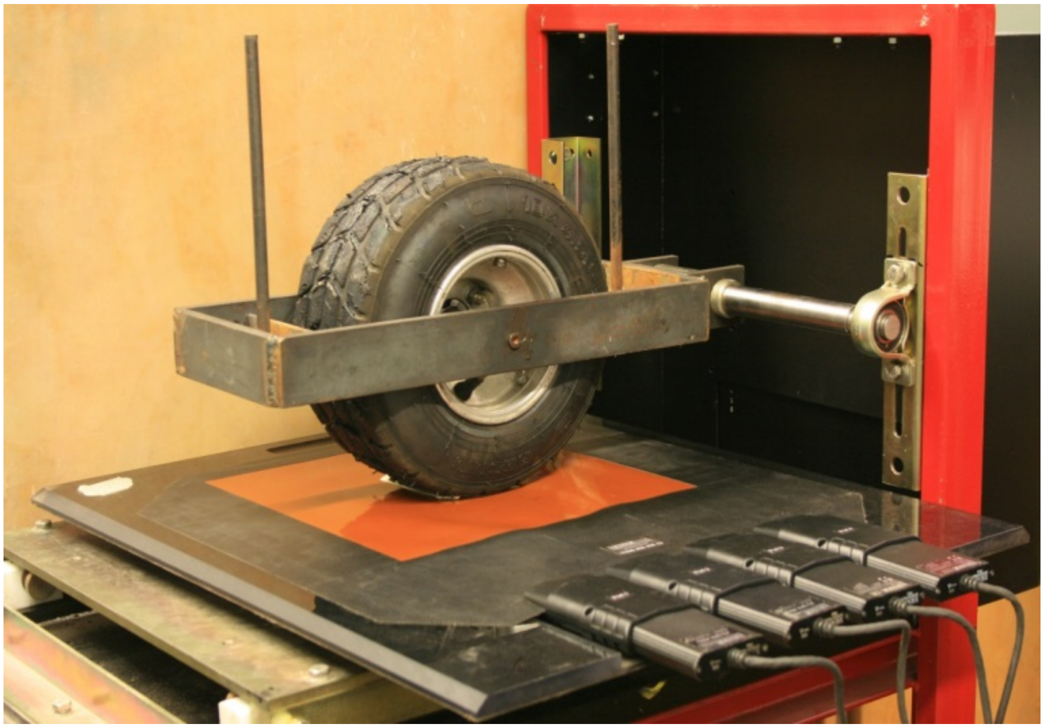


Figure 3. Measurement of test tyre contact patch using a high resolution XSensor pressure pad.

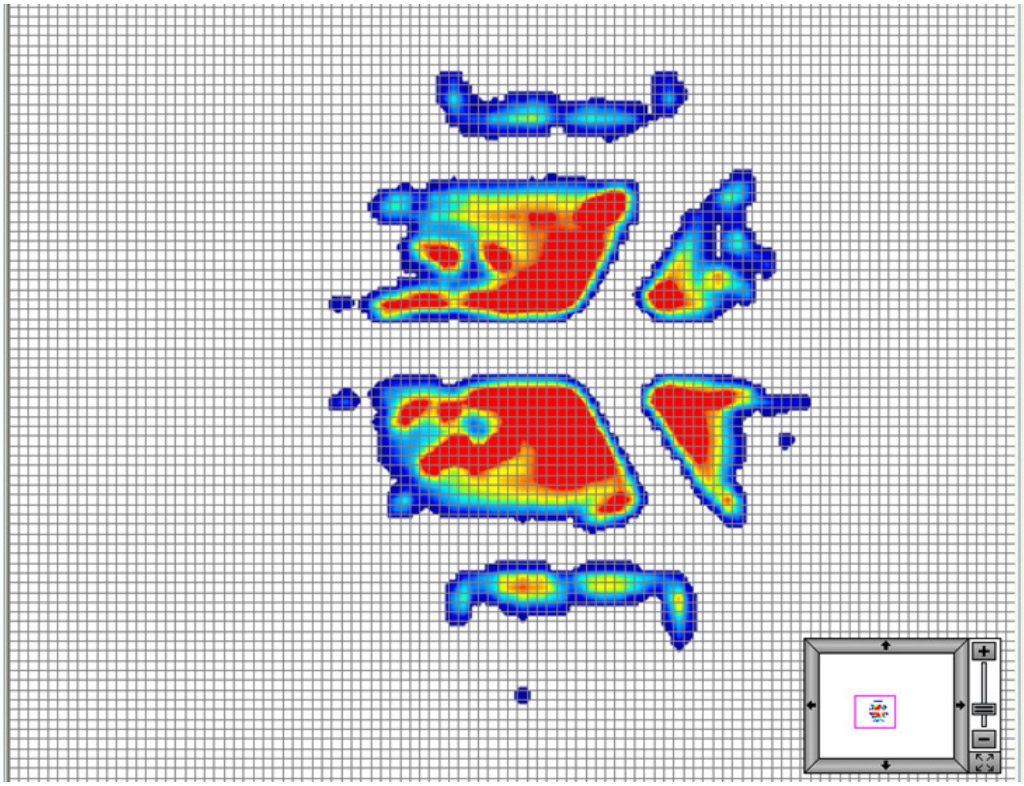


Figure 4. Contact patch for loading condition C with a tyre inflation pressure of 18.5 psi.

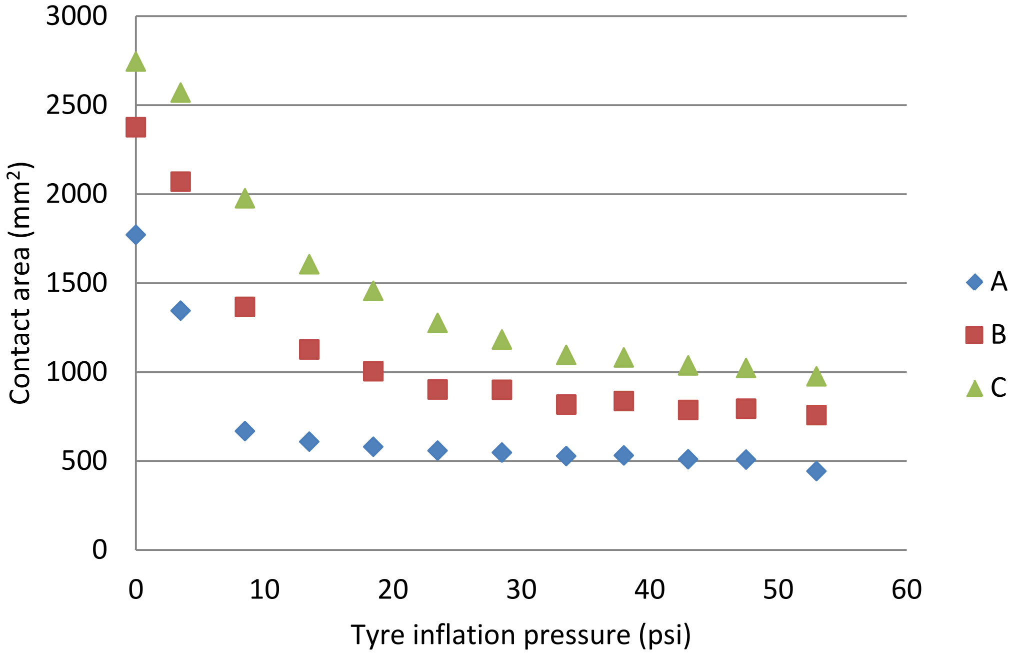


Figure 5. Contact area v. tyre inflation pressure for the 3 loading conditions.

Figure 6. The pneumatic test tyre and braking system.

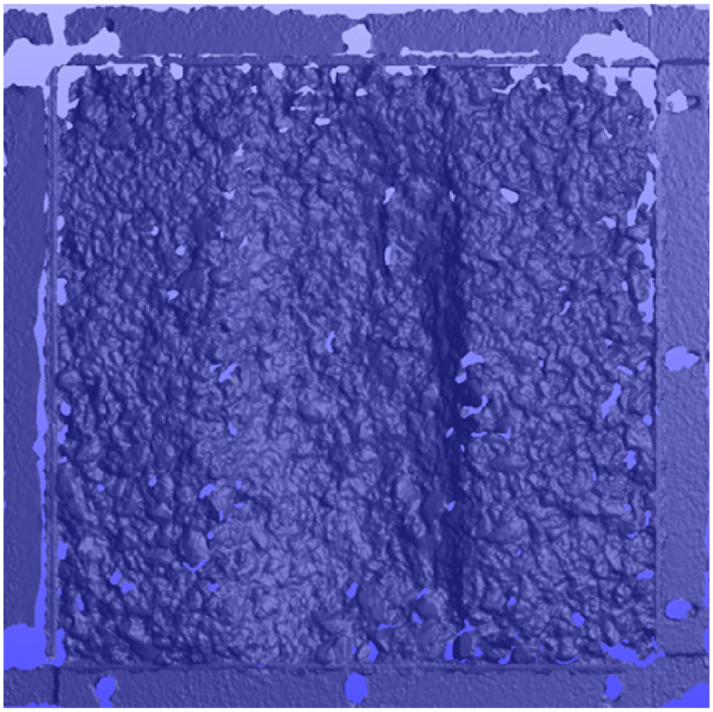


Figure 7. Example of a cleaned 3D model showing reference mould.

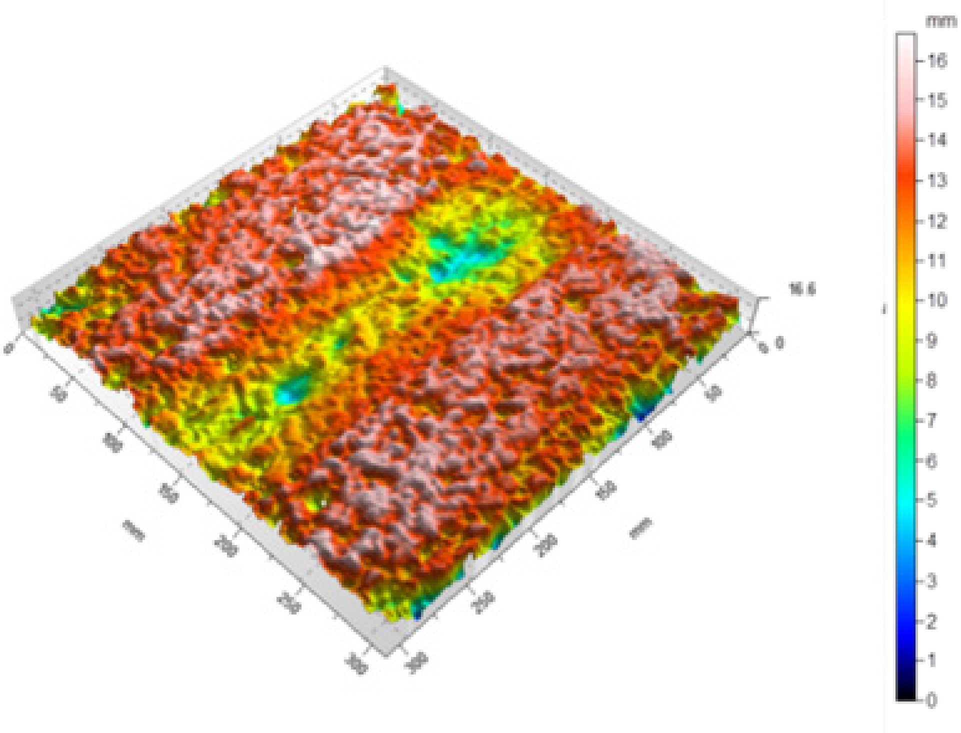


Figure 8. SMA10 post-test - poorly compacted

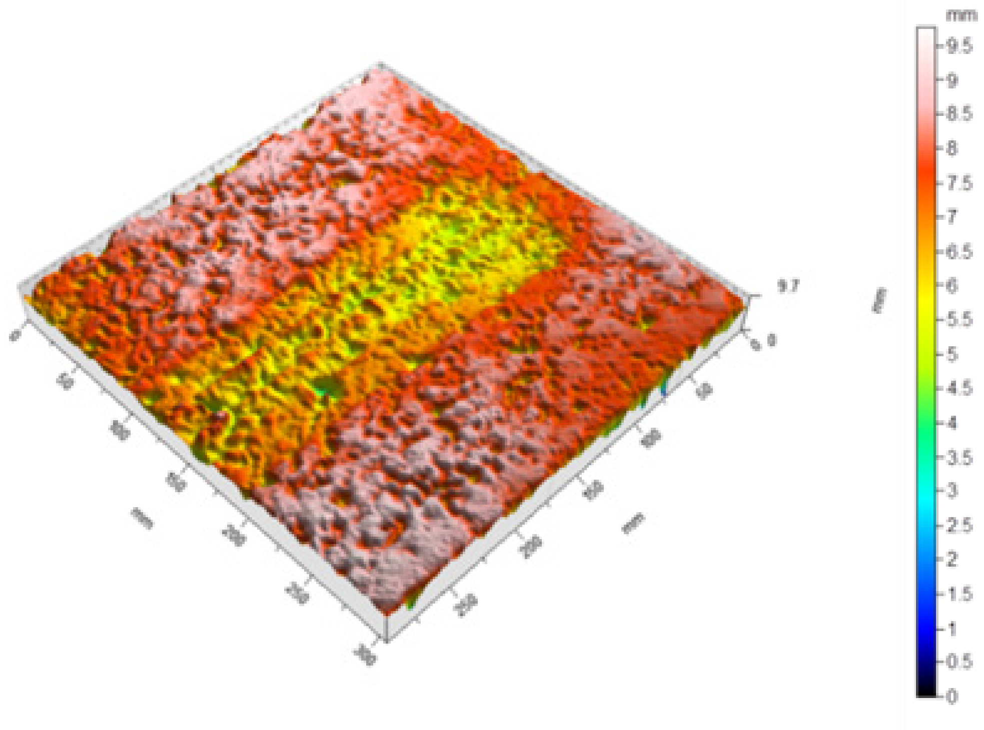


Figure 9. SMA10 post-test - well compacted

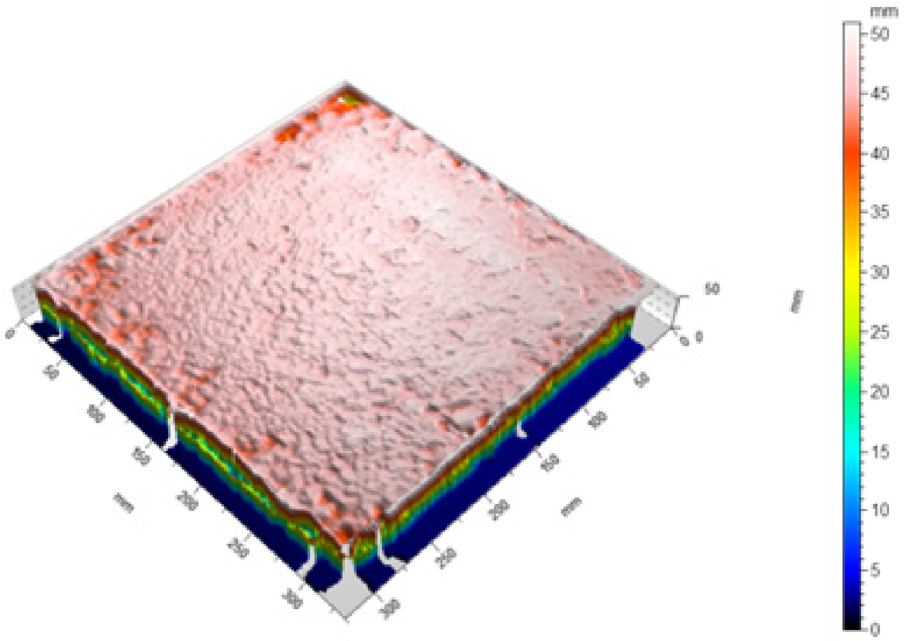


Figure 10. Example of poorly compacted test specimen 3D model prior to testing showing reference mould.

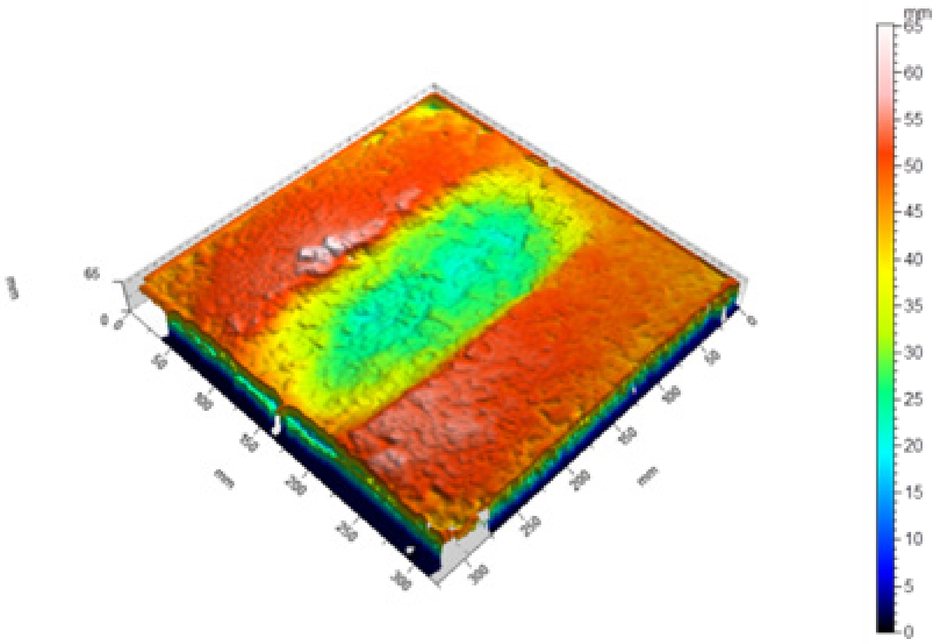


Figure 11. Example of poorly compacted test specimen 3D model after testing showing reference mould.

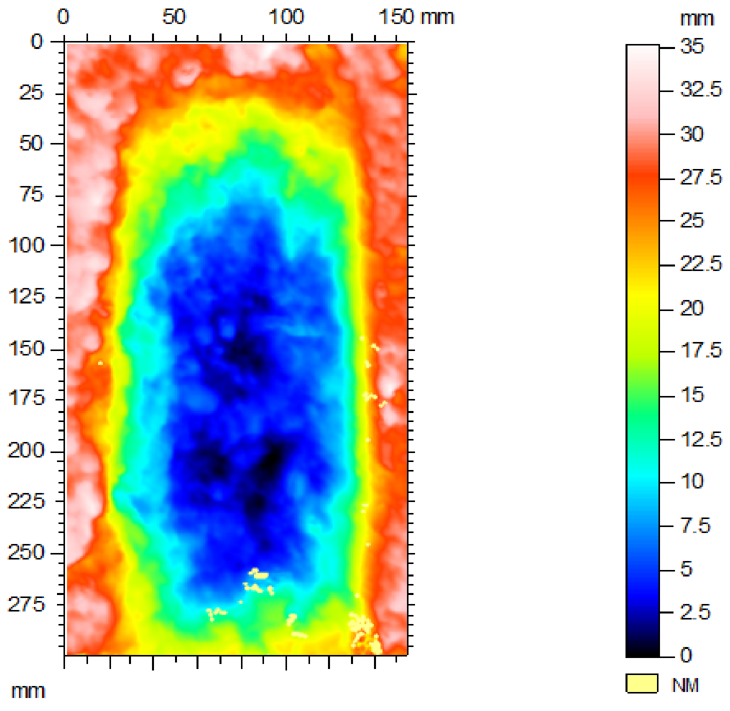
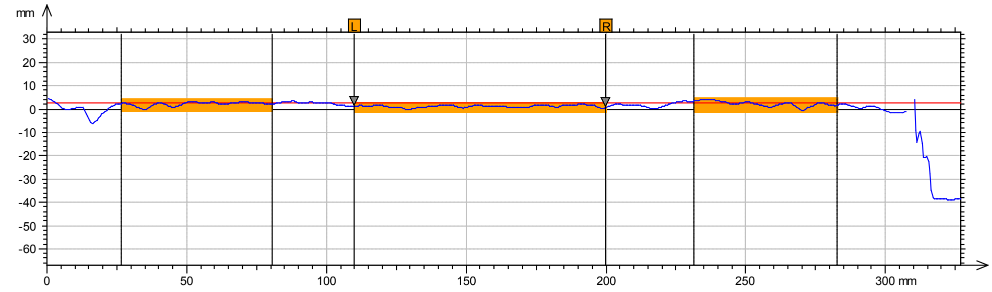


Figure 12. Example of a defined Area of Interest used for volumetric analysis.



	1
Maximum height	2.46 mm
Mean height	1.02 mm
Width	90.6 mm

Figure 13. Example of Step Height Measurement.

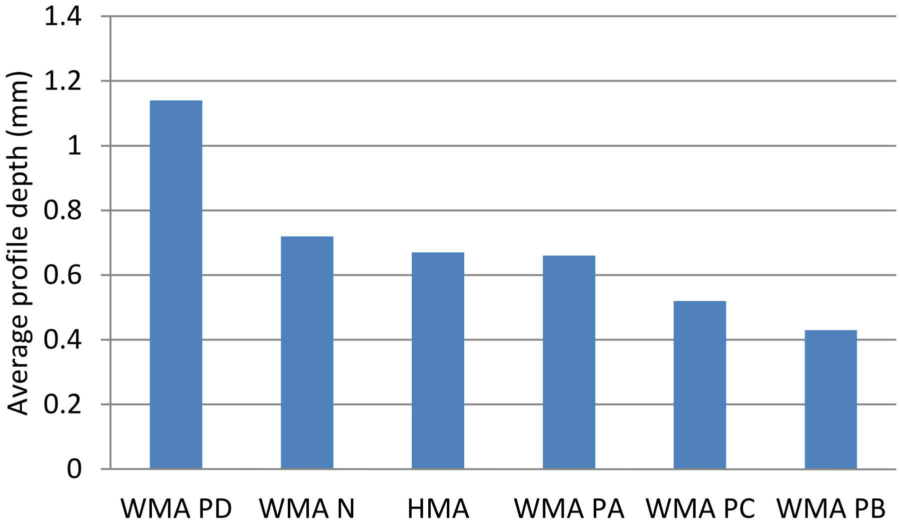


Figure 14. SMA14 mixtures ranked according to average profile depth.

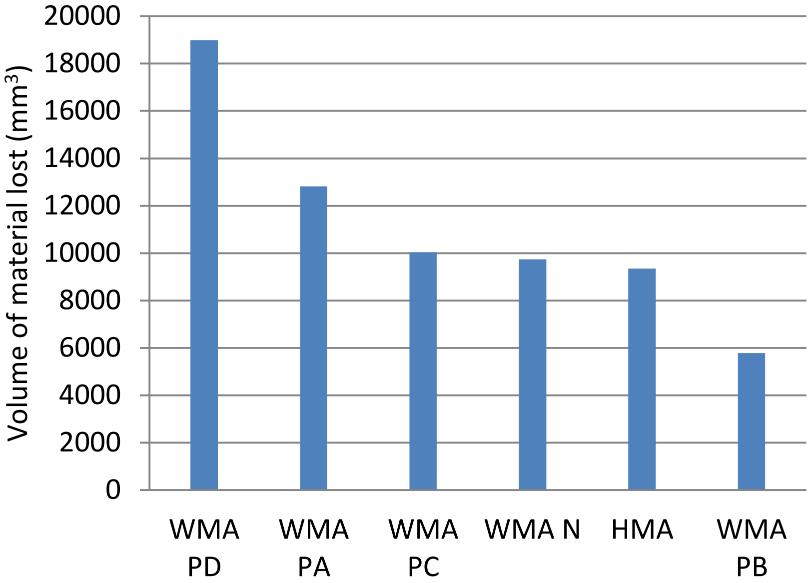


Figure 15. SMA14 mixtures ranked according to volume of material lost.