THE DEVELOPMENT OF ASPHALT SURFACING PROPERTIES

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ABSTRACT

This paper considers how the development of asphalt surfacing properties can be predicted in the laboratory. The research has been prompted by the ideals of sustainability coupled with the practical issues being faced by many countries around the world of how to improve, better manage and maintain their highway network. The properties of different types of asphalt surfacing evolve in different ways with time in relation to interactions with factors such as trafficking and climatic conditions. The examples given illustrate a range of methods that help understand these interactions and offer better prediction of likely in-service performance.

1. INTRODUCTION

Rapid economic development over the last 20 years prompted Ireland to be called the Celtic Tiger. This development was accompanied by major investment of €8 billion (Euro) in its highway infrastructure over a 10 year period [1]. However, in common with many countries the amount of new construction has reduced due to world recession. Although the period 2008 to 2011 saw a reduction in traffic volumes of approximately 7% it is forecasted that traffic volumes will return to peak levels in 2013/2014 and continue to grow at a rate of 2.5% per annum up to 2017 [2].

Ireland is also known for its 40 shades of green. This is a reflection of its Atlantic influenced weather i.e. not too cold in winter, not too hot in summer with rain distributed throughout the year. However, during the period 2008-2011 the severity of rainfall events have been greater than average [3] and caused highway pavements to be saturated for much longer periods of time. The winter of 2010 saw new extreme temperatures of -20C in many parts of Ireland with many roads subjected to freeze/thaw damage [4].

Ireland has abundant sources of high quality aggregate suitable for asphalt pavement construction. A wide range of asphalt surfacing mixes are used including Hot Rolled Asphalt [5], Asphalt Concrete [6], Stone Mastic Asphalt [7] and Proprietary Thin Surfacing Systems [8]. These are expected to achieve and maintain a level of in-service performance whilst meeting the ideals of sustainable construction.

In its wider context sustainability implies a holistic system. With regard to the asphalt mix used in the surfacing layer the ideals of sustainability combine conflicting factors in the current changing climate of funding and weather. These range from the expectation of the surfacing to be smooth, safe and quiet for longer periods of time to the problems of maintaining an existing asset at acceptable levels with reduced budget.

Some see the need to make significant reductions to emissions associated with asphalt production [9]. Whilst ways of reducing emissions and the use of sustainable products are needed, it is equally important that roads are durable to withstand traffic and climate conditions. Asphalt that is not durable is a false economy, leading to the more frequent maintenance and disruption.

Durability of surfacing asphalt layers has been defined as maintenance of the structural integrity of compacted material over its expected service-life when exposed to the effects of the environment (water, oxygen, sunlight) and traffic loading [10]. Good asphalt design is a balance of different properties e.g. durability, skid resistance, resistance to deformation, quiet ride quality, rolling resistance.

Their order of importance may change depending on country, the amount of funding available or in-service use. Being able to improve this balance implies better understanding of performance and the means of predicting it in the laboratory.

This paper considers developing research into the ability to understand and better predict asphalt material properties by considering the impact of trafficking and climate change factors such as traffic loading, rainfall, freeze/ thaw and exposure to de-icing salts. Examples are given to show how the impact of early life development of these factors may be predicted.

2. DEVELOPMENT OF ASPHALT PROPERTIES

The properties of all types of asphalt surfacing evolve with time. These include skid resistance, texture depth, the bitumen mastic, tyre / asphalt contact area / stress. The following summarise investigations to help model the interaction of these early life properties.

2.1. Skid resistance

The development of skid resistance for an asphalt mix is typically assumed to be dependent on the removal of bitumen and the exposure of aggregate in the trafficked surface. There is a period of variation before the onset of exposed aggregate polishing to equilibrium conditions. This period is known as early life and can last up to 2 years [11, 12, 13, 14].

Many factors influence development of early life skid resistance, including aggregate type, bitumen type, asphalt mix/type, nominal stone size, trafficking and environmental conditions. Figure 1 plots an example of early life skid resistance development for 8 hot mix asphalt surfacing mixes made with the same Silurian greywacke aggregate. Table 1 shows the binder contents for each mix.

This data relates to Cooper roller compactor slabs subjected to simulated trafficking using the Road Test Machine (RTM) located at University of Ulster. The development of wet skid resistance was determined at regular intervals using the British Pendulum Tester. The RTM is shown in Figure 2 and consists of a 2.1m diameter table that rotates at 10 rpm. Ten 305mm x 305mm x 50mm test slabs are mounted on the table and trafficked using two vertically mounted tyres each applying a load of approximately 5kN.

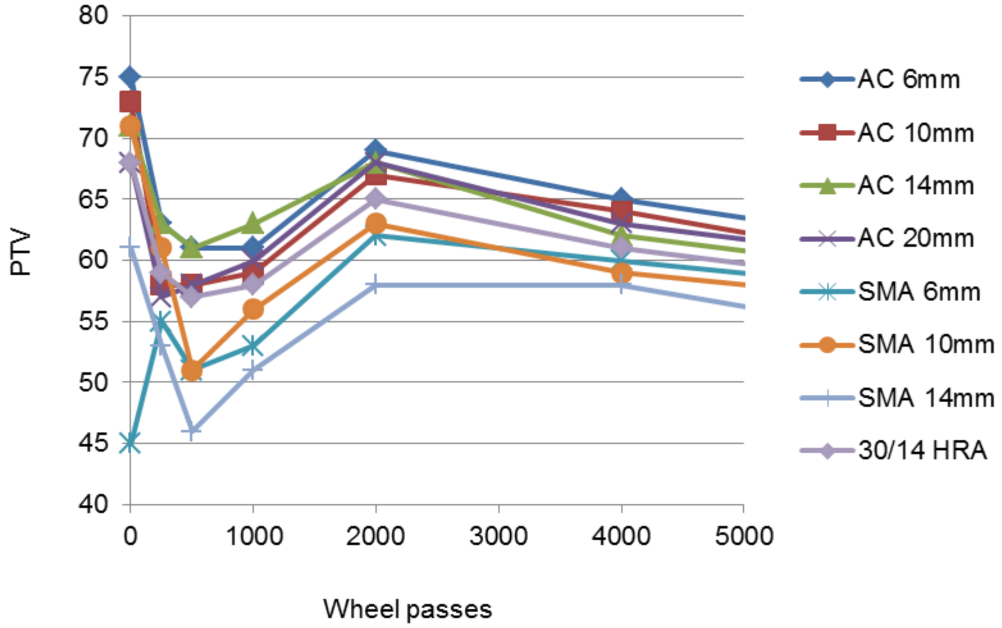


Figure 1 - Development of early life skid resistance [15]

Table 1 - Binder Contents of Asphalt Mixes

Asphalt type	Abbreviation	Binder Content (%)
Asphalt concrete	AC 6mm	5.4
	AC 10mm	5.0
	AC 14mm	4.9
	AC 20mm	4.2
Stone mastic asphalt	SMA 6mm	6.9
	SMA 10mm	6.1
	SMA 14mm	5.6
Hot rolled asphalt	30/14 HRA	7.6

Figure 2 – The Road Test Machine

This type of testing using full-size tyres allows comparison of actual asphalt mixes under controlled laboratory conditions. Despite all the mixes being made with the same aggregate there is variation in Pendulum Test Value (PTV) during the early stages of simulated trafficking. This reflects the interaction of factors such as grading, bitumen content, texture depth and tyre / asphalt contact area. The mixes show a decline in PTV after 500 wheel passes followed by an increase to 2,000 wheel passes and thereafter a decrease towards equilibrium.

The AC mixes tend to have higher PTV than the SMA mixes and by 5000 wheel passes have a ranking in relation to nominal coarse aggregate size i.e. the smaller sized mixes have higher PTV. There would appear to be a further relationship with bitumen content i.e. the SMA mixes have higher contents than the AC mixes and lower PTV.

2.2. Texture depth

Figure 3 shows the evolvement of early life texture depth, measured using the sand-patch test, for the same asphalt mixes shown in Figure 1. This shows a general decrease during the first 5,000 wheel passes. An initial drop in the first 250 wheel passes for most of the mixes relates to removal / smearing of binder/mastic coating of the trafficked surface. Although texture depths for most asphalt mixes should not significantly change during their early stages of testing, any sudden increase relates to the onset of a durability problem such as ravelling. This becomes more prevalent during the later stages of this type of full-scale testing.

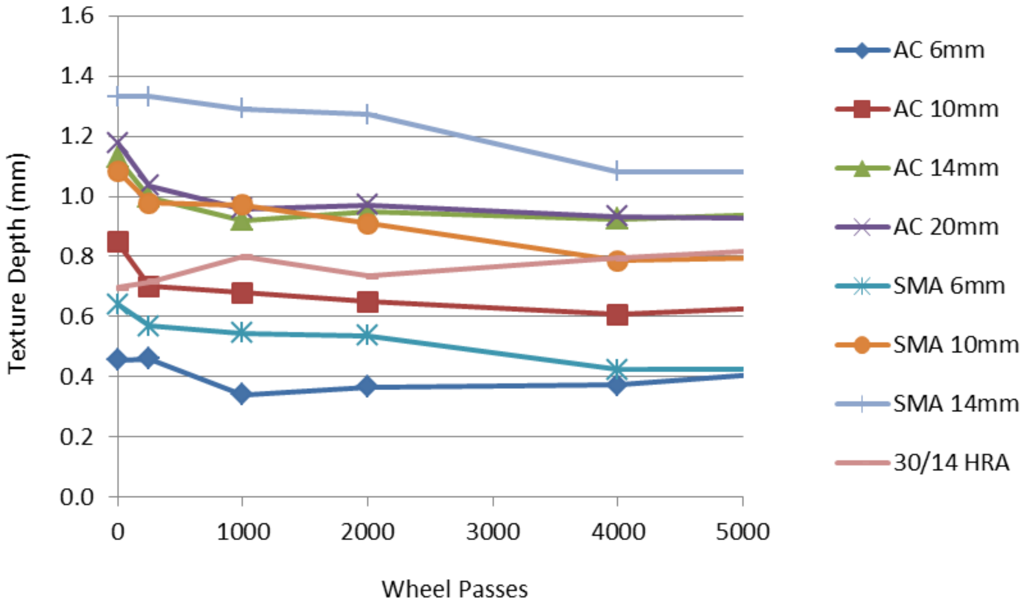


Figure 3 - Development of early life texture depth measured using sand-patch [15]

2.3. Bitumen / mastic

Many asphalt mixes are modified with fibres or use polymer modified bitumen to improve their durability. These have a bitumen/mastic coating on the exposed trafficked surface that is either thicker or has greater bond with the aggregate particle compared to more traditional types of unmodified mix. Figure 4 shows how the bitumen/mastic coating of different types of asphalt can influence the measurement of skid resistance using the British Pendulum Tester.

This plots the number of pendulum swings to achieve 3 consecutive readings as the test slabs were subjected to dry simulated trafficking using the RTM. The three asphalt materials shown are 30/14 Hot Rolled Asphalt with 20mm pre-coated chippings, 20mm AC and 14mm SMA with binder types of 40/60 pen, 100/150 pen and a polymer modified bitumen (PMB) respectively. Initially, when the aggregate is coated with bitumen, the 20mm AC required 37 pendulum swings followed by 20 swings for the 30/14 HRA and 16 swings for the 14mm SMA. Thereafter the number of swings decreased until stable conditions were finally reached after 10,000 wheel passes. This may be explained by the percentage and grade of binder used in the mixes and the eventual exposure of aggregate.

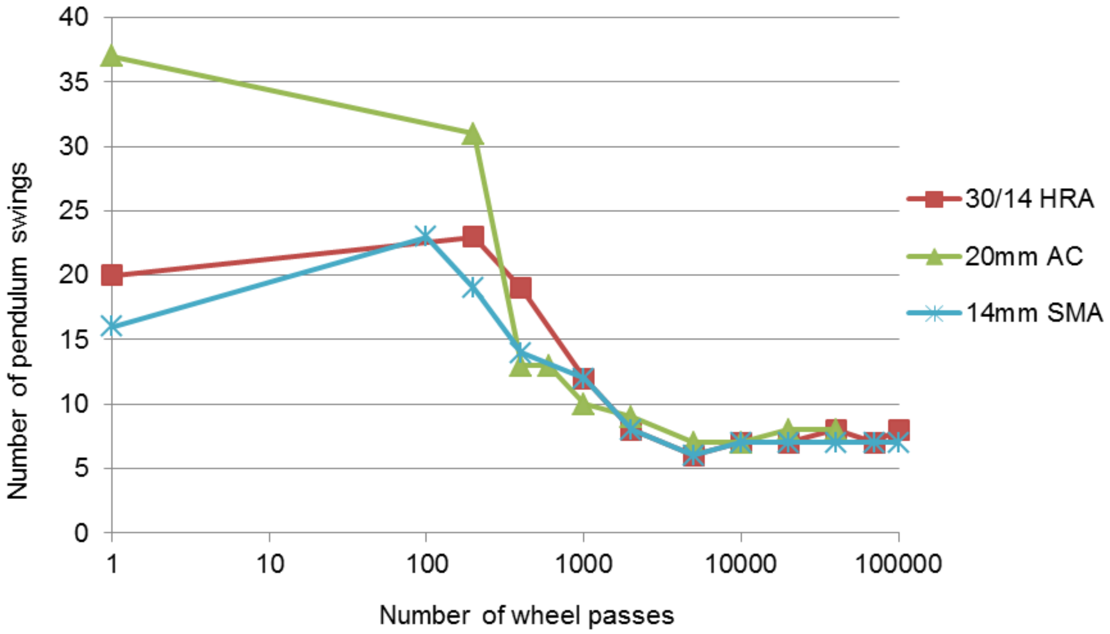


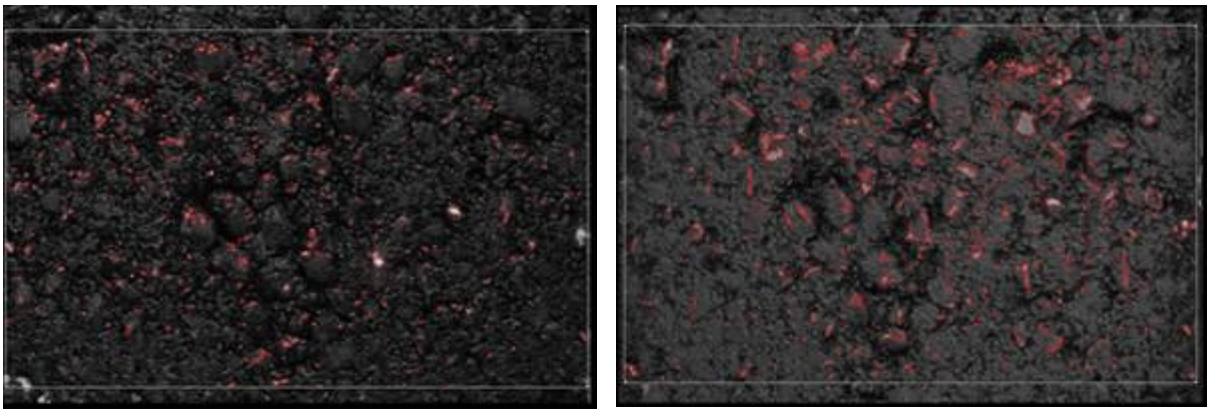
Figure 4 - Number of pendulum swings to get 3 consecutive readings the same

2.4. Aggregate exposure

Figure 5 shows the development of aggregate exposure for a 20mm AC test slab made with limestone during dry simulated trafficking on the RTM. Digital photographs were taken at the various intervals and assessed using ImagePro software to measure aggregate exposure. The red outline shows the areas of exposed aggregate. The small amount of aggregate exposure prior to simulated trafficking is due to the roller compactor during slab manufacture.

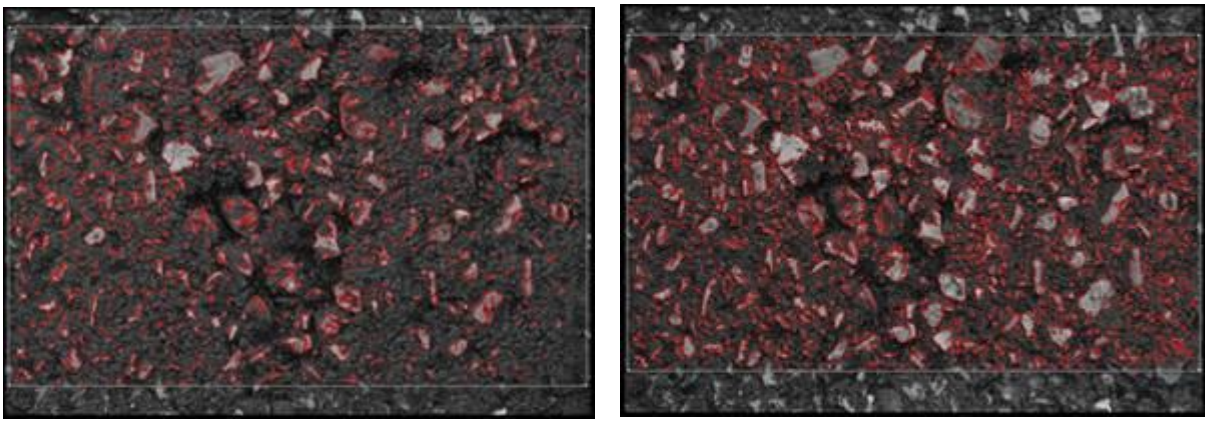
At 2,000 wheel passes the larger sized aggregate particles are becoming exposed. The bitumen has dulled in colour and is smearing across the surface infilling surface voids. With continued trafficking the coarse aggregate continues to become exposed with the finer sizes becoming evident.

Figure 6 plots the development of PTV (wet skid resistance) and percentage aggregate exposure during simulated trafficking. This shows a reduction of 25 PTV points for only 4% aggregate exposure during the early stages of simulated trafficking. With continued testing the reduction in wet skid resistance slowed significantly whilst the amount of aggregate exposure continued to almost 20% of the total slab surface.



Aggregate exposure 0 wheel passes

Aggregate exposure 2,000 wheel passes



Aggregate exposure 40,000 wheel passes

Aggregate exposure 100,000 wheel passes

Figure 5 - Aggregate exposure for a 20mm Asphalt Concrete

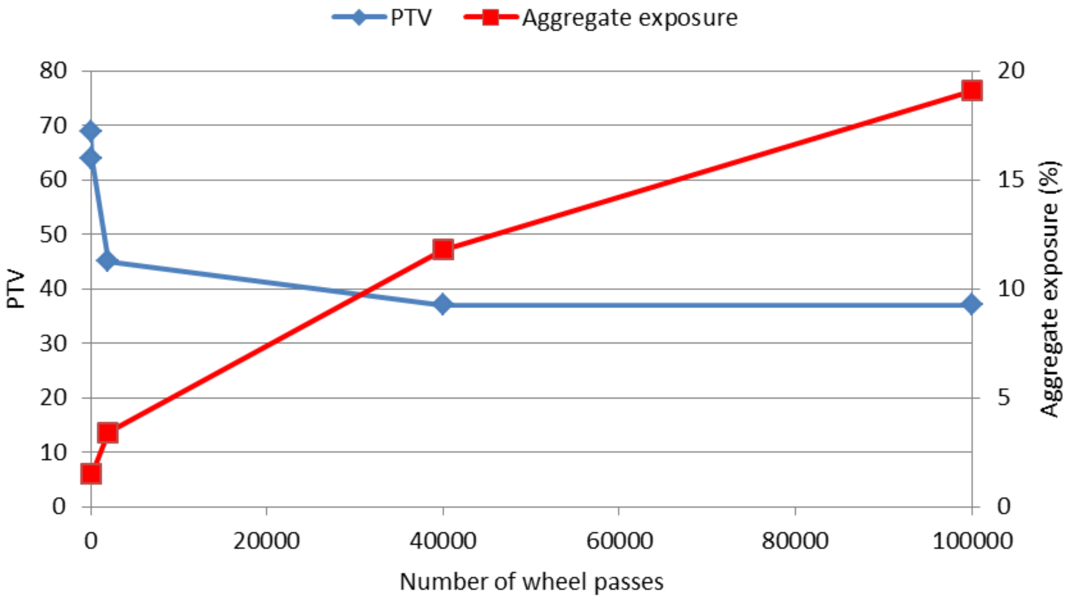
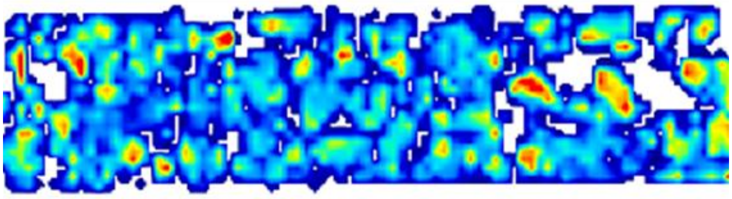


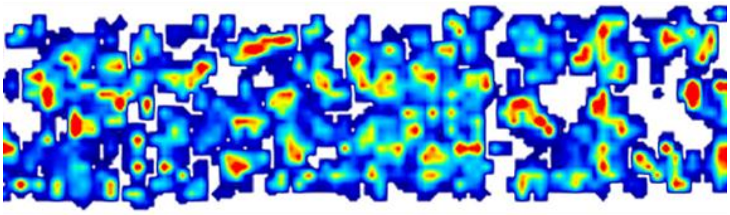
Figure 6 - Development of PTV and aggregate exposure for a 20mm Asphalt Concrete

2.5. Tyre / asphalt contact area / stress

Figure 7 shows 2D contact area / stress plots for the same part of a 14mm AC test slab after 0 and 20,000 wheel passes. The 2D images were obtained using a methodology that combines three main components i.e. a modified Wessex wheel tracking machine, a GripTester tyre and XSENSOR pressure mapping sensor. The test equipment is shown in Figure 8.



A. 0 wheel passes



B. 20,000 wheel passes

Figure 7 - Contact area / stress distribution plots for a 14mm Asphalt Concrete

The Wessex wheel tracking machine was modified to enable the XSENSOR pressure system to be placed on top of an asphalt test sample and be moved dynamically under a loaded tyre [16]. As temperature control is not important, the environmental chamber of the standard Wessex wheel tracker has been removed.

Figure 8 – Test equipment to measure tyre / asphalt contact area / stress

A standard pneumatic GT tyre was used to replace the solid wheel tracking tyre of the Wessex wheel-tracker equipment. GripTester [17] is used around the world to measure grip. Use of its tyre in this methodology allows correlation of laboratory and field data. The wheel tracker lever arm was modified to accommodate the extra width of the GT tyre compared to the solid rubber tyre. The GT tyre load can be varied using weights applied to the lever arm of the wheel tracking machine.

This setup allows either static or dynamic measurements to be taken from either the tyre and / or at the interface between the tyre and an asphalt surface. Test specimens of different asphalt mixes can be prepared using roller compactor or gyratory techniques. These can be assessed in either static or dynamic condition before and at different stages of simulated trafficking to track changes in contact properties.

The XSENSOR data can be displayed in 2D or 3D view. 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 CAD or spatial GIS modelling software.

Figure 7 shows both contact area and the distribution of contact stress for this test slab to have changed during testing from 0 to 20,000 wheel-passes i.e. contact area decreased whilst stress distribution became more localised and concentrated. Figure 9 illustrates how contact area data measured using this method can be related to other properties such as texture depth and wet skid resistance measured using pendulum. In this example, the % contact area relates to the contact area measured for the asphalt slab expressed as a percentage of the contact area measured for a glass plate under the same conditions.

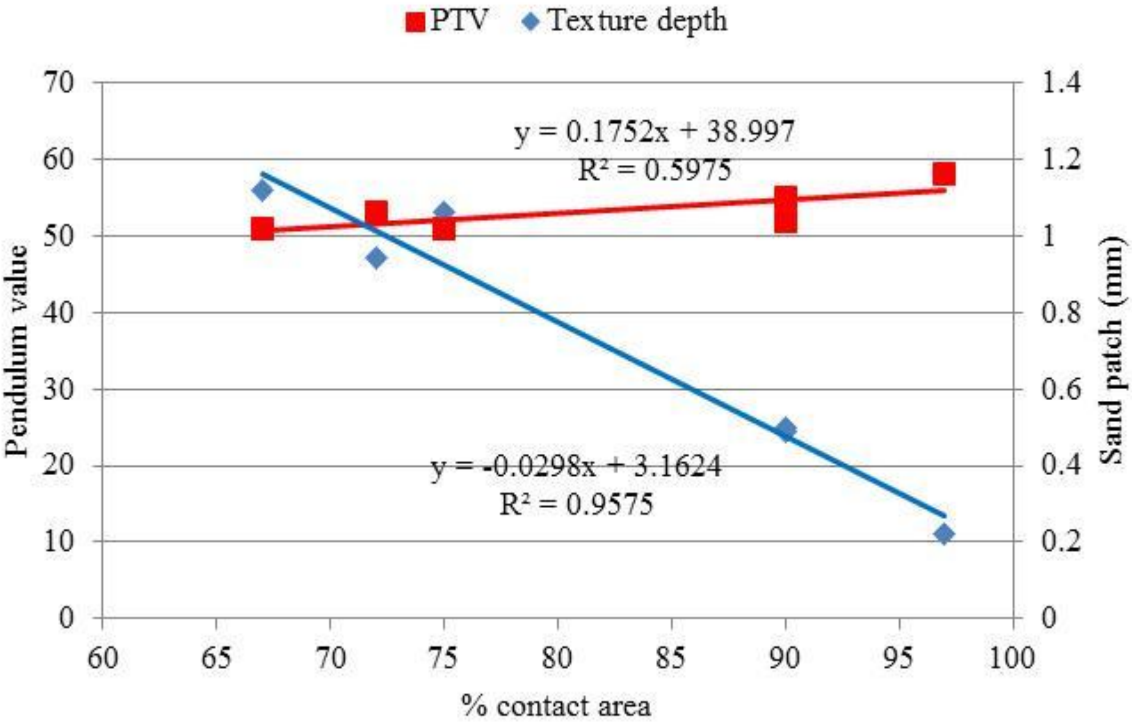


Figure 9 – Contact area v. wet skid resistance and texture depth

2.6. Durability

Sustainable highway construction implies the use of materials that will perform at adequate levels for longer periods of time [18]. The need to maintain performance during engineering life has renewed interest in asphalt durability. Premature failure has occurred when a pavement loses its functionality or no longer remains in a serviceable state. The current economic climate and subsequent reduction of highway maintenance budgets has put more emphasis on the need to get the mix right first time and to deliver durable pavements with lower maintenance requirements.

There are two basic components in an asphalt mix i.e. bitumen and aggregate. Most research considers bitumen. However, aggregate makes up the bulk of an asphalt material. A review of current standards, specifications and guidance documents relating to aggregates in bituminous mixtures was carried out [19, 20]. Whilst this identified a wide range of test methods, the current guidance documents recommended that many are not required in the UK.

For example, they state that there is no need to assess fines for harmful content. Testing which takes account of the effect of salt on durability was not acknowledged i.e. the Freeze thaw test with salt [21]. This is despite research showing that the combination of salt and freeze / thaw can have a significant detrimental effect on surfacing aggregates [22]. The role of fine aggregate in asphalt mix properties such as strength and durability appears to be not fully acknowledged.

Two experiments now report the contrasting role that the same poor quality aggregate plays in the durability of an asphalt mix [23]. Figure 10 illustrates the effect of its addition as coarse aggregate and as fine aggregate after asphalt sample conditioning and simulated trafficking.

A – as coarse aggregate replacement B – as fine aggregate replacement

Figure 10 – AC slab showing difference between coarse and fine aggregate replacement

In the first experiment the coarse aggregate was replaced by poor quality aggregate. In the second experiment the fine aggregate was replaced. In both experiments the same highly weathered Tertiary basalt was used. This had been selected by hand and crushed in the laboratory to the required sizes. The poor quality highly weathered basalt had high water absorption of 10% and completely failed the magnesium sulphate soundness test after 2 of the standard 5 cycles.

Roller compactor 20mm AC slabs were prepared using aggregate blends made with increasing amounts of poor quality basalt i.e. 0, 3, 6, 12 and 18%. This was used to replace the coarse aggregate content (>10mm). A good quality Carboniferous limestone was used as the main mix aggregate. The slabs were split into 2 groups. Group 1 had no conditioning i.e. they were tested as made and acted as controls. Group 2 were conditioned by 5 cycles of soaking in water for 24 hours followed by freezing to -18^{0}C for 48 hours. They were allowed to thaw out in the lab during the day.

After conditioning all 10 slabs were subjected to simulated dry trafficking for 70,000 wheel passes using the Road Test Machine. All slabs stood up well to dry simulated trafficking. The trafficked poor quality basalt particles quickly lost any binder coating and were plucked from the surface by the tyre.

Figure 10A shows the freeze / thaw slab containing 18% weather basalt after 40,000 dry wheel passes. This shows the slab was not overly compromised by this loss of coarse aggregate. This may be partially due to the use of the limestone aggregate i.e. it polished quite quickly and so there would have been less interaction with the tyre compared to a higher PSV aggregate.

Figure 11 plots the change in wet pendulum value for both sets of slabs and shows that increasing amounts of poor aggregate had relatively little impact on pendulum value (in the legend, Slab 18B represents the freeze /thaw slab with 18% poor quality aggregate)

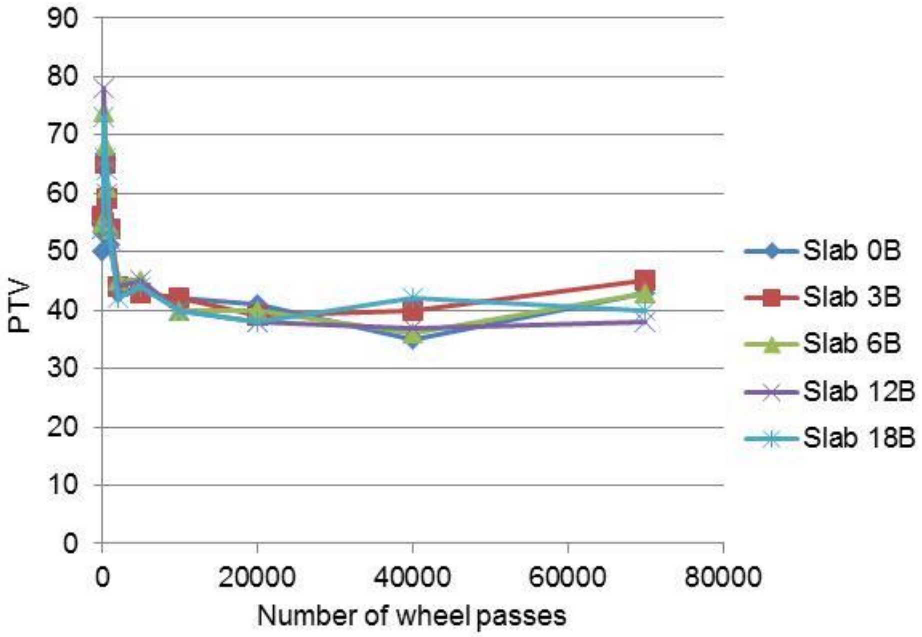


Figure 11 - Change in wet pendulum value

In the second experiment, 50% of the fine aggregate (<2mm) was replaced with the same poor quality basalt used in the coarse aggregate replacement experiment. This was approximately 16% of the overall aggregate content in the mix. 150mm diameter 10mm AC test specimens were made using gyratory compaction. The rock type selected for the remaining aggregate content was good quality Tertiary basalt.

The test specimens were split into 4 groups for conditioning prior to simulated trafficking in the Road Test Machine. Group 1 was left in a dry condition to act as a control. Group 2 were subjected to five freeze/thaw cycles. Each cycle consisted of soaking in water for 48 hours followed by freezing at -18^{0}C for 24 hours. Group 3 were subjected to five wet / dry cycles i.e. soaked in water for 48 hours and left to dry out on a bench top for 24 hours. Group 4 were subjected to five cycles of soaking in salt water for 48 hours followed by drying out on the bench top for 24 hours.

After each conditioning cycle the stiffness of each test specimen was measured using the Nottingham Asphalt Tester and subjected to 2500 wheel passes of simulated trafficking on the Road Test Machine. Testing was stopped after 5 conditioning cycles and 12,500 wheel passes.

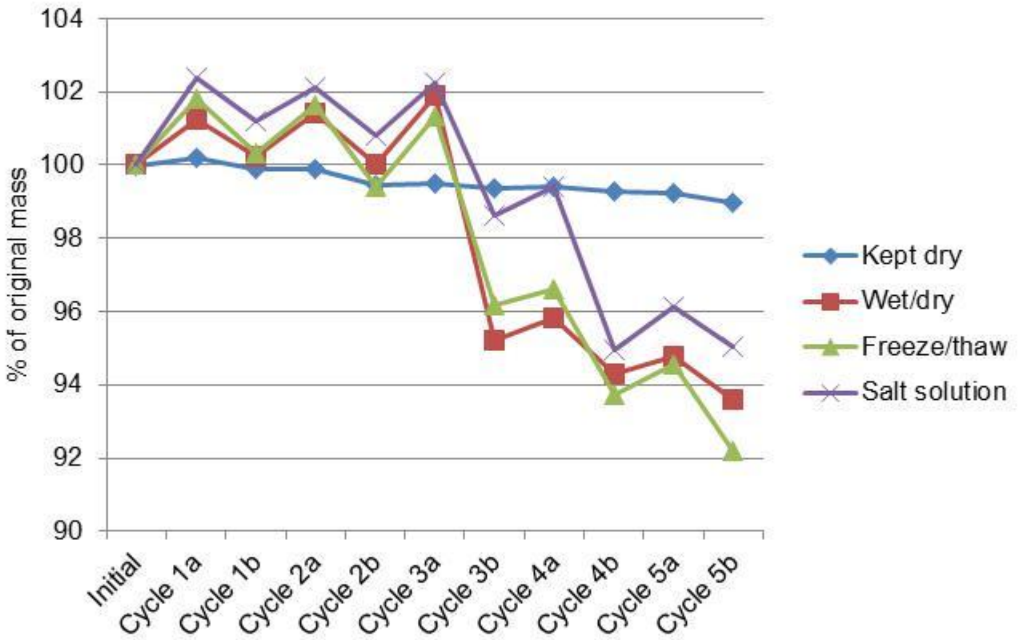


Figure 12 - Change in test specimen mass due to type of conditioning

Figure 12 shows the change in test specimen mass expressed as a percentage of its original mass. The control samples that had been kept dry remained in a worn but acceptable condition at the end of testing. Each test specimen containing the weathered basalt that was soaked either in water or salt solution and / or frozen suffered initial swelling and a small increase in mass due to water soaking into the asphalt mix.

During the early stages of simulated trafficking they lost fine aggregate. After three conditioning cycles there was the onset of significant surface ravelling of the coarse aggregate during simulated trafficking (see Figure 10B).

Figure 13 shows the change in mix stiffness of the 150mm diameter test specimens measured using the Nottingham Asphalt Tester. The data shows the test specimens containing the weathered basalt to have initial stiffness values up to 3 times greater than those made with 100% good basalt.

The test specimens containing the weathered basalt fines that were kept dry lost stiffness at a slow and gradual rate comparable to the 100% good basalt test specimens. However there was a rapid loss in mix stiffness after the first conditioning cycle for the test specimens that were either soaked in water or salt solution and / or frozen i.e. test conditions that represent real life in-situ conditions.

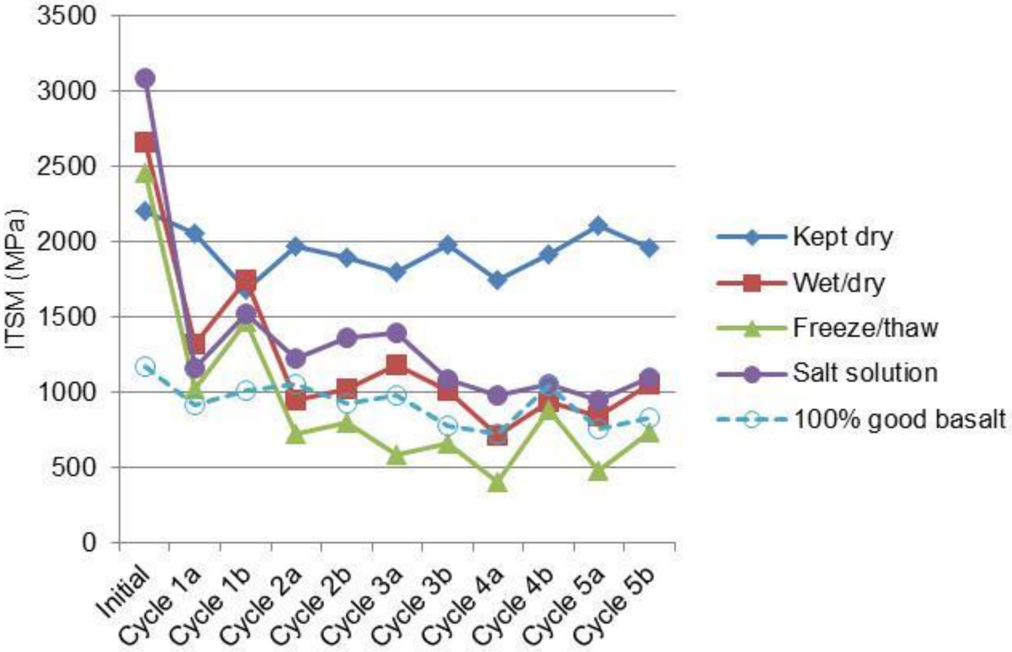


Figure 13 - Change in mix stiffness due to type of conditioning

These two experiments are part of study to find a laboratory methodology to better predict asphalt mix durability. By selecting an aggregate that fails quickly, the effect of its use in the mix, either as the coarse or fine aggregate component can be easily evaluated. Test specimen conditioning must consider the Irish climate e.g. wet / drying, freeze / thaw, the use of salt for de-icing. Tyre / asphalt surface interaction forces simulated by the Road Test Machine exploits weaknesses within the asphalt mix.

These two experiments show the same poor quality aggregate behaved differently when used as different particles sizes. Its presence was most apparent when used as fine aggregate. The test specimens most affected were those that had been subjected to repeated freeze / thaw conditioning. However, the experiment clearly showed that water was central to the destructive process and regardless of ambient temperature failure occurred.

As Ireland has an average yearly rainfall of 970mm and 171 wet days [24] i.e. its road network spends a significant part of the year wet, better prediction of asphalt properties needs to consider this factor.

3. DISCUSSION

The modern asphalt pavement surface is expected to be smooth, safe, quiet and sustainable. Irish research is addressing this in relation to current economic climate and an increasingly fluctuating weather patterns in Ireland. The paper has concentrated on two properties i.e. predicting the early-life development of skid resistance and durability.

Examples have been given to show some of the interacting factors that need to be understood and appreciated. When an asphalt mix is subjected to simulated trafficking, the development of its surfacing properties will vary during its early life until equilibrium is reached. Skid resistance may initially drop to potentially unsafe levels as bitumen/mastic and aggregate exposure develops increasing wet skid resistance.

The example showing number of pendulum swings may highlight a scenario of higher bitu-planing risk. Smearing of the binder/mastic coating appears to partially infill surface texture and/or initially mask the benefits of using higher skid resistance aggregate for potentially quite long periods of time. This infilling of surface texture may influence surface water drainage and aquaplaning or lead to the development of surface void water entrapment, accelerating deterioration of the surface due to hydrostatic pressures caused by vehicle tyre pumping.

Failure to recognise the effects of weather or actions taken to deal with frost are not considered in the UK when testing asphalt materials. The role of poor quality aggregate differs when used as coarse or fine sizes. These are issues that need to be considered as they can result in un-expected premature failure.

4. CONCLUSION

Hot Mix Asphalt surfacing properties will vary during early life development. This is not due simply to the aggregate, bitumen or mix types used, but rather a combination of many factors including how vehicle tyres interact with the asphalt surface.

Simulated trafficking using a full-scale tyre allows better insight into what effect bitumen / mastic coatings on the trafficked aggregate particle may have during early life. It may be removed quickly or smear across the surface partially infilling surface texture. This has the potential of masking the beneficial properties of a high specification aggregate for quite long periods of time unless there is sufficient trafficking.

This infilling of surface texture may increase the risk of aquaplaning as surface drainage of water could be significantly reduced. It could also lead to the development of surface void water entrapment, accelerating deterioration of the surface due to hydrostatic pressures caused by vehicle tyre pumping.

Aggregate exposure increases with simulated trafficking, as would be expected. However, the rate of aggregate exposure for different asphalt materials can differ as a result of bitumen type and grade used within an asphalt mix. The exposure of finer material between coarser aggregates may be contributing to skidding resistance in the later stages of simulated trafficking.

Contact area and stressing conditions on aggregate particles vary over time. The measured dynamic contact decreased with increasing number of wheel passes. Contact area has the potential to effect properties such as skidding resistance, texture depth, aggregate wear and polishing, and durability.

Early life skid resistance is only one part in the life of an asphalt surfacing. Later, skid resistance will reach equilibrium in relation to asphalt, trafficking and environmental conditions. During this later period durability issues may / will become more prevalent. In the UK there is no true durability test that can be used to predict how long as asphalt may continue to perform.

The same poor quality aggregate to behave differently when used as coarse or fine particles sizes. Its detrimental presence was most apparent when used as fine aggregate. The test specimens most affected were those that had been subjected to repeated freeze / thaw conditioning. However, it clearly showed that water was central to the destructive process and regardless of ambient temperature failure occurred.

Test specimen conditioning should consider a countries climate e.g. the Irish climate involves repeated wet / drying throughout the year, some freeze / thaw during the winter and the use of salt for de-icing.

To conclude, this paper has considered current developing research being carried out looking the better understanding the development of asphalt properties in Ireland. This work is finding methods and techniques to better understand performance of asphalt materials and how these may be predicted in the laboratory.

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