International Conference on Sustainable Infrastructure and Built Environment in Developing Countries
November, 2-3, 2009, Bandung, West Java, Indonesia
ISBN 978-979-98278-2-1

Review of Sustainable Asphalt Surfacing Research

David Woodward
Faculty of Art Design and Built Environment, University of Ulster
Newtownabbey Northern Ireland
wdh.woodward@ulster.ac.uk

Abstract
This paper considers current research into improving the sustainability of asphalt surfacing materials in the United Kingdom. The overall aim of the research has been to reduce risk and encourage the ideals of sustainability in the provision of road surfacing materials. The research has involved the use of standard and specialist laboratory techniques, test facilities and in-service measurement. The methodologies have been proven in collaborative research projects that have resulted in better understanding of material performance and failure characteristics. They have been used to develop new surfacing materials with enhanced performance characteristics.

Keywords: asphalt, performance, prediction, sustainability.

1. Introduction

The ideals of sustainable highway construction have resulted in many changes over the past 10 to 15 years. Many different types of asphalt mix, specifically designed to offer a wide range of enhanced performance characteristics have been developed in the United Kingdom and Ireland. Skid resistance has always been a priority with factors such as rut resistance and public demand for quieter surfacings in urban areas important. However, awareness of global climate change, increasing energy costs, transport issues, scarcity of natural resources and the introduction of 25 year+ maintenance contracts has promoted considerable interest in properly understanding the materials being used and developed.

The over-riding issue of risk has highlighted that much greater knowledge is required of the materials being used both in the structural layers and at the tyre / asphalt surface. A combination of all these factors has resulted in a big picture scenario whereby this paper is placed. The simplistic assumption that good texture or use of hard aggregate equals safer longer lasting roads is not a sustainable option if the aggregate or mix only lasts for a limited number of years failing prematurely. It is now essential to understand and quantify what happens to materials with time.

This paper reviews different areas of research carried out the University of Ulster into sustainable highway construction to improve the prediction of asphalt surfacing material performance. The research is based on existing recognised standard methods such as PSV and GripTester measurements. It considers the importance of non-standard test methods, unique test equipment and predictive methods of assessment that is essential to better understand the fundamental reasons why different materials may perform in different ways during their in-service life. The methods have been used to explore the early life, equilibrium and mature phases in the life of asphalt surfacing materials as they either polish to unsafe levels or suffer types of surface failure such as ravelling.

2. Aggregate Contribution to Performance

In the UK the polish stone value test (PSV) has been used for over 50 years to assess the friction characteristics of aggregates used in highway surfacing materials. Woodside (1981) investigated the PSV test method with Woodward (1982) relating PSV to the petrology of Northern Ireland Silurian greywacke. Woodward has subsequently been involved in many research projects relating the petrology of Irish, UK and overseas rock-types to properties such as PSV, abrasion, strength and soundness. This underlying knowledge helps provide basic understanding and explain the fundamental relationships between rock type, skid resistance and other surfacing properties such as ravelling. Woodward (1987) considered calcined laterite as a replacement to imported high friction calcined bauxite from South America and China.

Widajat (2001) investigated Indonesian andesite with Peterson et. al. (2002) reporting a comparison of basaltic aggregates from Indonesia, Iceland and Ireland. Woodward (1995) critically evaluated the PSV test to other methods and specifically concentrated on variations related to rock type. The basic conclusion was that PSV and other typical specified test methods do not adequately assess surfacing aggregate in terms of predicting in-service performance.

In response to research by Roe and Hartstorne (1998) Roe and Woodward (2004) reported the findings of a TRL project that attempted to predict skid resistance from the polishing properties of the aggregate. This research identified that a single aggregate could deliver a range of skidding resistance under apparently similar conditions and highlighted that a fundamental barrier to improving the specification of polishing resistance is the inadequacy of understanding the detailed physical mechanisms of aggregate polishing under today's traffic conditions.

Woodward (2003) further developed this research and developed new test methods e.g. to assess the effect of applied bitumen coatings on PSV moulds. This was found to have a significant influence on the development of skid resistance. These methods found that the standard PSV test is not a measure of an aggregates ultimate state of polish but simply an equilibrium value that relates to the test conditions.

3. Early Life and Very Early Life Skid Resistance

UK guidance on levels of skid resistance measured using equipment such as SCRIM and GripTester assume that an asphalt surface reaches a level of performance equilibrium after a period of 1 to 2 years. There is seasonal variation with an overall downward trend to a value at which the surface warrants investigation prior to possible resurfacing or some other type of treatment. However, research carried out in the last few years has highlighted that there are distinct periods particularly during the early life of road surface materials. In the 1990's a number of accidents and press reports in the UK highlighted a period before this equilibrium period during which it was claimed that certain types of road surface material may become slippery both when wet and in dry conditions i.e. problems with aquaplaning and bitu-planning.

Woodward (2003) assessed the in-service development of skid resistance at trial sites located in Ireland and the UK. This period of research coincided with the development of specialised proprietary types of asphalt surfacing now used in the UK and Ireland. The laboratory and in-service research concentrated on predicting the development of early life skid resistance for asphalt mixes ranging from SMA made with cellulose fibres, unmodified / polymer modified bitumen; porous / semi porous mixes to the use of smaller stone size thin surfacing systems.

Correlation of the modified laboratory methods being developed with in-service data allowed better understanding of the risks involved, particularly where previous experience was not present (Jellie, 2003). GripTester was used to obtain the values of wet grip. Typically, it is found that there are reductions in wet friction over the first few days, weeks or months. This time period is referred to as very early life and varies depending on asphalt mix, aggregate / bitumen combination and in-service conditions. For example, asphalt made with high skid resistance aggregate and polymer modified bitumen may actually perform quite poorly in its early life and has prompted the use of slippery road signs and / or reduced speed limits across the UK and Ireland to warn the public were these types of asphalt surfacing materials are laid.

4. Laboratory prediction of noise and rolling resistance

Issues such as road noise and fuel efficiency are very important in terms of sustainable highway construction. Both properties are directly related to the road surface and prompted research into developing laboratory methods to predict these properties without the need for full scale road trials. The ULTRA apparatus is an internal rotating drum test device that is used to investigate high speed surface tyre interactions such as skidding, noise and rolling resistance.

Yaacob (2006) and McErlean (2006) developed methods to specifically assess the effect of road surface texture on the development of noise generation and rolling resistance respectively. Yaacob and McErlean developed respective indices that allow ranking of noise and rolling resistance in relation to surface texture. This found that reducing the surface texture equates to lower noise generation and better rolling resistance or fuel efficiency.

This example clearly shows how the combination of road surface texture and reduced nominal stone size relates to more sustainable highway design i.e. improved fuel use or less noise in high populated areas.

5. Measurement of Asphalt Wear

Improved sustainable highway construction implies the use of materials that will perform at adequate levels for longer periods of time. However, it is difficult to test the durability of asphalt materials in conditions similar to those experienced in-situ. The use of simple methods such as wet/dry testing of asphalt plugs using Marshall stability or Indirect Tensile Stiffness Modulus does not consider the effect of traffic stressing.

This has prompted considerable research into assessment of the wear characteristics rather than simple moisture sensitivity. The Road Test Machine (RTM) consists of a rotating table on which 10 slabs 305x 305 x 50mm in size are subjected to accelerated trafficking using 2 full-size tyres. The equipment is housed in an environmental chamber that controls test temperature and subjects the test slabs to accelerated wear. The development of properties such as skid resistance is measured using the British Pendulum Tester with texture depth measured using the sand patch method.

The RTM is currently accredited by the British Board of Agrément to assess the wear characteristics (Nicholls 1997) of High Friction Surfacings (HFS) for Highways Authorities Product Approval Scheme (HAPAS) accreditation. HAPAS was set up in the 1990's with the objective of developing national approval arrangements for innovative products, materials and systems for use id highways and related areas. A high friction surfacing is a proprietary system typically consisting of a 3mm calcined bauxite aggregate bonded to the asphalt surface using an epoxy extended bitumen binder. The HAPAS process is a series of laboratory tests and monitoring of road trial sites over a 2 year period. The effect of accelerated trafficking is assessed by measuring change in texture depth and skid resistance after 100,000 wheel passes.

The RTM has been used to assess the wear characteristics of a wide range of asphalt materials including hot rolled asphalt, porous asphalt, bitumen macadam, asphalt concrete, micro-asphalt, proprietary thin surfacings to generic SMA with and without the application of grit to improve their early life skid resistance. These asphalt investigations typically involve making 305 x 305 x 50mm slabs from materials sampled on-site or mixed in the laboratory. This allows combinations of aggregate and bitumen to be easily and quickly assessed without the need for full-scale road trials under controlled repeatable conditions.

Testing is periodically stopped, particularly during the early stages of testing and change in skid and texture depth recorded using sand patch and pendulum tester. This allows four distinct periods in the life of an asphalt surfacing material to be determined and ranked against other types. The presence of water can substantially reduce friction between dry and wet test conditions. The presence of water can also change the ranking of asphalt mixes in dry and wet conditions. Use of the RTM allows for the quick evaluation of materials. For example, the application of 3mm grit to 14, 10, 8 and 6mm generic SMA to assess whether it can reduce potential early life skidding issues. This found the 6mm nominal size mixes to have better wet skid resistance than the larger sized mixes with the application of 3mm grit improving early life skid resistance. GripTesting of sites were these materials were laid is finding that the smaller nominal sized mixes are giving higher values of skid resistance.

6. Assessing Skid Resistance of Asphalt Systems in the Laboratory

Two test methods are currently being considered in the UK to assess skid resistance of the asphalt system i.e. the unique aggregate grading and bitumen combination, rather than just the 10mm aggregate component. The two methods are the German Wehner Schulze (WS) and the Road Test Machine (WS). The WS subjects 260mm diameter cores to high speed polishing whereas the RTM is a much slower wear test. Both equipments allow assessment of the asphalt system and offer much better optimisation of materials. Allen et. al. (2007) and Walsh (2009) summarise the use of these equipments to test UK asphalt mixes rather than simply the aggregate.

7. Assessing the Effect of Water on Asphalt Performance

Global climate change models predict that the UK and Ireland will experience more severe rainfall events more often. In terms of the road user, the asphalt surface will have low levels of wet friction for longer periods of time. The increased amounts of water will also cause increasing reduction in the life of the asphalt due to weakening of the aggregate particles and the aggregate/bitumen bond. This issue of water affecting the longer term performance of asphalt surfacing materials has been a subject of research across the world for many years. Typically the research has conditioned cores or plugs made in the laboratory by soaking them in water and carryout out simple strength or repeated loading type tests.

In terms of highway design and the choice of asphalt materials, Nursetiawan (2008) assessed the surface flow and internal flow characteristics of asphalt surface material finding relationships with cross fall, texture depth and rainfall intensity. Repeated simulated rainfall wetting and drying cycles was used to condition test specimens for assessment of moisture sensitivity damage. Change in skid and texture effects were quantified under simulated trafficking using the RTM equipment (Nursetiawan et. al. 2008). This methodology is currently forming the basis of a new testing protocol being developed at the University of Ulster to assess the effect of water on the durability of asphalt surfacing materials.

8. Assessment of Surface Textures

Measurement of asphalt surface texture using sand patch offers limited information with laser techniques requiring expensive equipment. Millar et. al. (2009) considered the use of 3-d image analysis based on simple digital camera stereo images. The images are quick and easy to take and using proprietary ImageMaster software allowing 3-d models to be generated. This image can then be assessed using other software such Civil 3D CAD to determine volume and contact area data. The 3-d modelling techniques have been applied to textures ranging from the millimetre, sub-millimetre and micron level. This research is currently developing the work of Liu (1993) and Siegfried (1999) in the measurement of interfacial stressing to quantify surface texture changes and the dissipation of surface water under a moving tyre.

Tyre foot-print information measured using a Xensor Pressure Mat will be superimposed with the 3-d modelled surfaces and provide new insights into tyre / asphalt interfacial stress within the contact patch. This will then be combined with the asphalt surface hydrographs developed by Nursetiawan (2009). A minimum level of texture is required of the road surface to assist the tyre tread in the displacement of water within the road surface / tyre contact patch. However, there are many different types of texture from dense to porous.

The use of rainfall run-off hydrographs show how it is now possible to better understand how a surface deals with rain-water. The aim is to optimise the removal of water, either by a network of interconnected surface channels or by a network of interconnected internal voids. However, current research is showing that small scale surface depressions, that give high levels of texture depth, trap surface water and may be having significant detrimental impacts on the durability of the asphalt by concentrating the harmful effects of hydraulic loading, freeze / thaw or de-icing materials.

9. Vehicle Dynamics and Changes in Skid Resistance

The effect of vehicle dynamics on the skid resistance of smaller stone size / lower texture asphalt mixes laid at high speed race tracks in Ireland and the UK is currently being investigated. GIS software is used to plot a GripMap. This consists of GPS referenced GripTester data that shows longitudinal and lateral variation in wet grip. Vehicle dynamic data can be overlaid on this GripMap to show the level of grip for any part of the track surface. The GIS based maps clearly show the racing line and the high levels of stressing experienced at the bends.

The measurement resolution is currently being improved to offer centimetre accuracy in terms of position and will enable very detailed investigation of how skid resistance develops across a wheel-path in relation to car wander in different lane widths. This data is being compared to vehicle dynamics such as longitudinal and lateral g-variation. Initial findings show direct correlation between these g-forces and development of measured grip. It is expected that this will provide application to understanding how grip developments in higher stress locations such as corners and braking/acceleration areas.

10. Conclusions

This paper has summarised different areas of research that have a common theme i.e. sustainable highway surfacing asphalt. Their collective aim is to illustrate the complexity of the factors involved and emphasise that reliance on standard test methods will not provide the necessary in-depth understanding to help predict, design, test or specify. The materials used in modern asphalt surfacing mixes are exposed to conditions not adequately accounted for in current specifications or test methodologies leading to poor or over performance. Greater knowledge of the materials being used and the interconnection of properties is now an essential pre-requisite to sustainable highway construction practise.

11. References

Allen, B., Phillips, P., and Woodward, W.D.H. (2007). Comparison of laboratory skid resistance measurement techniques. 5th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control (MAIREPAV5) Utah, August 8-10.

HD36 Surfacing Materials for New and Maintenance Construction, (2006). UK Design Manual for Roads and Bridges.

Jellie, J. (2003). A study of factors affecting skid resistance characteristics. PhD thesis, University of Ulster.

Liu, G. X. (1993). The area and stresses of contact between tyres and road surface and their effects on the road surface. PhD thesis, University of Ulster.

McErlean, P. (2006). A study of the relationship between texture depth, rolling resistance and noise for highway surfacing materials. PhD thesis, University of Ulster.

Millar, P., Woodward, W.D.H. and Woodside, A.R. (2009). Use of close range terrestrial photogrammetry to assess accelerated wear of asphalt concrete surface course mixes. Mairepav 6 Conference, Torino, Italy 8^{th} to 10^{th} July. Edited by Ezio Santagata, ISBN 978-88-8202-0293.

Nursetiawan. 2009. The hydraulic properties of asphalt materials. DPhil Thesis, University of Ulster.

Nursetiawan, Woodward, D. and Strong, A. (2009). Predicting the effect of rainfall on asphalt surfacing materials. Sixth International Conference on Maintenance and Rehabilitation of Pavements and Technological Control. Politechnico di Torino, Italy July 8-10. Edited by Ezio Santagata, ISBN 978-88-8202-0293.

Petursson, P., Woodward, W.D.H., Bjornason, G. & Widajat. D. 2002. Comparison of Basaltic Aggregates from Iceland, West Java and N Ireland. 9th Nordic Aggregates Research Conference, 12-14 September, Reykjavik, Iceland.

Roe, P.G. and S.A. Hartshorne. 1998. The polished stone value of aggregates and in-service skidding resistance. TRL Report 322, Transport Research Laboratory.

Roe, P.G. and W.D.H. 2004 Woodward, Predicting skid resistance from the polishing properties of the aggregate (SKIDPREDICT) Final Report PR CSN/31/03. Report prepared for Highways Agency, CSS and Quarry Products Association.

Siegfried. (1999) The study of contact characteristics between tyre and road surface. PhD thesis, University of Ulster.

Widajat, D. (2001) Predicting the performance of basaltic aggregate for use in unbound road base and sub base layers. DPhil Thesis, Faculty of Engineering, University of Ulster.

Walsh, I. (2009) Reduced use of High PSV Aggregate in Thin Surfacing. Contract 2/462. Prepared for UK Highways Agency.

WOODSIDE , A.R. 1981. A study of the polishing of roadstones. MPhil thesis, Ulster Polytechnic.

WOODWARD, W.D.H. 1982. The relationship between petrology and PSV for a Co. Down greywacke aggregate. Final year project, Ulster Polytechnic.

WOODWARD, W.D.H. 1987. An investigation of Northern Ireland calcined bauxites and laterites for use as hard wearing skid-resistant aggregates. Master of Philosophy thesis, Department of Civil Engineering, University of Ulster.

Woodward, W.D.H. 1995. Predicting the performance of surfacing aggregate. DPhil Thesis, Faculty of Engineering, University of Ulster.

Woodward, W.D.H., IGR Report GR/R09022/01, Predicting Early Life Skid Resistance of Highway Surfacings (SKIDGRIP), EPSRC funded project, final report, 2003.

Woodward, W.D.H., Woodside, A.R., Ellis, R., Phillips, P. Walsh, I. and R. Sinhal. 2008. The effect of aggregate type and size on the performance of thin surfacing materials. Safer Roads Conference, Cheltenham, England.

Yaacob, H. 2006. A study of the effect of texture on surface dressing characteristics, PhD thesis, Faculty of Engineering, University of Ulster, UK.