Stone Mastic Asphalt – A review of its noise reducing and early life skid resistance properties

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ABSTRACT

Traffic noise is generated from the network of roads forming the matrix of an urban environment and impacts residents everywhere. As a result of the gradual tightening of noise limits imposed by legislation tyre/road noise has become the dominant traffic noise source particularly in free-flowing traffic at speeds above 40-50 km/h. Numerous factors affect the production of tyre/road noise - speed and weight of vehicle, wear, tread and structure of the tyre and the road surfacing. Previous studies have concluded that there is greater scope for reducing tyre/road noise by redesign of the road surfacing than by redesign of the tyre. The main characteristics determining noisiness of road surfacings are geometrical features, acoustical and mechanical properties of the pavement. Two generation processes have been identified; one in the low frequency range is roughness induced vibration; the other in the high frequency range is ‘air-pumping’. Certain road surfacings such as Stone Mastic Asphalt (SMA) have modified surface textures which bring about reductions in noise however major concerns have been raised regarding the early life skidding resistance. This paper examines the acoustical benefits of the use of surfacings such as SMA and reviews evidence for the purported associated reduction in skidding resistance.

INTRODUCTION

Traffic noise is generated from the network of roads forming the matrix of an urban environment and impacts residents everywhere. The typical effects of traffic noise will be annoyance and interference with life in and around the home. In many developed countries, road traffic noise is considered to be one of the principal sources of environmental pollution.

In recent years priorities have shifted from emission control of the vehicles as far as their engine and exhaust noise is concerned, to the control of tyre/road noise. This has occurred due to the gradual reduction of engine and exhaust noise as a result of tightening noise limits and tyre/road noise therefore becoming the dominant traffic noise source particularly in free-flowing traffic at speeds of above 40-50 km/h. (von Meier, 1993) A number of road surfacings have been developed which reduce road traffic noise by approximately 2-3 dB(A), however there has been controversy recently regarding safety issues, specifically early life skid resistance.

This paper will present the structure of typical traditional and ‘quiet’ road surfacings, the mechanisms controlling the generation of tyre/road interfacial noise, and present a review of the current knowledge relating to the skid resistance performance of these ‘quiet’ surfacings.

TYPICAL ROAD SURFACINGS

Road pavements generally comprise a sub-base, a basecourse with an intermediate course and wearing course forming the surfacing layers. The wearing course of a road pavement must fulfil a demanding role - providing adequate skid resistance in dry and wet weather and a surface of acceptable riding quality, resisting deformation by traffic and cracking as a result of thermal movement or traffic stresses and contributing to the strength of the pavement structure. The bituminous wearing courses currently used in Australia are described briefly below.

Dense Graded Asphalt (DGA)

The most common type of asphalt is dense graded asphalt (DGA), also known as Asphaltic concrete, a mixture of continuously graded aggregates, sands, filler and bituminous binder which is mixed and forms an interlocking structure. This structure is the major contributor to the strength and performance of the laid material.

The durability and resistance to environmental degradation of DGA is largely determined by in-situ air voids typically 3-7%, and binder content, and it is important that these be optimised for service conditions. Maximum durability requires a high binder content to fill almost all the voids and reduce the permeability to water and oxygen, conversely achieving resistance to deformation under traffic demands good aggregate interlock, with stone to stone contact and thus some voids. Therefore a compromise must be achieved.

Binder type, aggregate characteristics, filler type, and use of additives, all contribute to structural stiffness, fatigue, deformation resistance, surface texture and workability.

Open Graded Asphalt (OGA)

Open graded asphalt is a uniformly graded bituminous mix using predominantly coarse aggregate and containing only small amounts of fine aggregate and filler resulting in a high percentage of air voids, typically 18 to 25%.

OGA relies largely on mechanical interlock of aggregate particles for stability. Being permeable, they are less durable than dense type mixes although durability is assisted by an increase in binder film thickness around the individual aggregate particles using high binder contents, and the use of modified binders. Coarse textured aggregates with angular shape are desirable for surface texture and stability.

OGA is not recommended for use at intersections due to relatively low shear resistance and potential for oil droppings to soften the binder and fill the voids, reducing drainage ability.

Stone Mastic Asphalt (SMA)

Stone mastic asphalt is a gap graded mix, with a high binder content and a high proportion of coarse aggregate providing an interlocking stone-on-stone skeleton giving good deformation resistance.

A bitumen rich mastic mortar binds the aggregate skeleton together, resulting in toughness and excellent durability. The mortar comprises crushed rock fine aggregate, filler, bitumen or modified bitumen and a stabilising additive. A very high binder content is essential to ensure durability and laying characteristics. Sufficiently high binder contents cannot be achieved using unmodified or unstabilised bitumens; drainage of bitumen or mortar would occur during transport and laying. Therefore, most stone mastic asphalt mixtures use a fibre stabiliser mixed with the binder in the mortar to keep it homogenous.

The durability of SMA is equal or greater than DGA and significantly greater than OGA. SMA is suitable for use at intersections and other high traffic stress situations where OGA is unsuitable.

ROAD SURFACING CHARACTERISTICS

The main characteristics determining the noisiness of a road surfacing are the geometrical features, notwithstanding some residual influences which can be traced as related to acoustical and mechanical properties of the pavements. (*Sound Effects*, 1996) The range of noise levels for different surfacings is considerably greater than the small differences resulting from the changes in tread pattern. This is one reason why it is generally considered that there is more scope for reducing tyre/road noise by redesign of the road surfacing than by design of the tyre.

Macrotexture and Microtexture Definitions

Three broad ranges of texture wavelength (λ) have been defined as having significantly different effects on tyre/road interactions. These are microtexture (texture of the aggregate particles, $\lambda < 0.5$ mm), macrotexture (overall texture of the road created by the disposition of the aggregate particles, $0.5 \text{ mm} < \lambda < 50 \text{ mm}$) and megatexture (evenness of the road, $50 \text{ mm} < \lambda < 500 \text{ mm}$). Microtexture and macrotexture are illustrated in Figure 1.

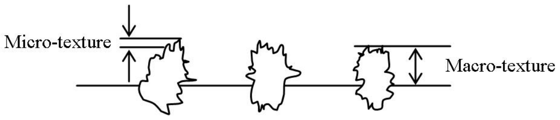


Figure 1. Microtexture and macrotexture

Measurement of Macrotexture and Microtexture

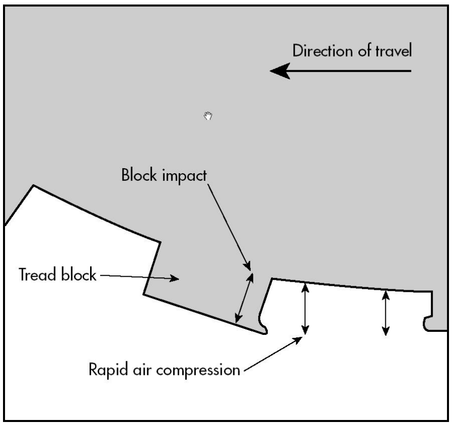
Microtexture is often specified by the polishing resistance of the aggregate measured using the Polished Stone Value (PSV) test or similar. The macrotexture can be quantified by the sand-patch texture depth (SPTD) test or more recently the use of a laser profilometer.

GENERATION OF TYRE/ROAD INTERFACIAL NOISE

The generation and propagation mechanisms of road/tyre noise are complex, however it is generally accepted that the mechanisms can be classified into 3 distinct source regions and generation mechanisms. (Walker, 1981). Figures 2-4 illustrate these mechanisms.

1. Leading edge of the tyre

At the leading edge of the tyre the tread blocks strike the road surface and subsequently vibrate. The frequency of these impacts is the tread pattern repeat frequency. On a smooth road the pattern repeat frequency of the tread blocks would be quite dominant although modern tread pattern design reduces this effect. The block impact effect on a rough road is similar, however there also exists some further influence from the road surfacing which breaks up the repeat effect.



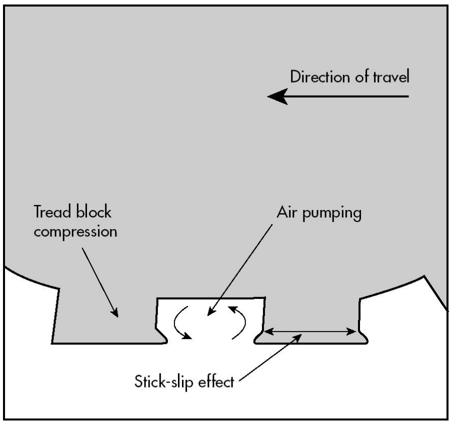
Source: (Nelson & Phillips, 1997)

Figure 2. Noise generation at the leading edge of the tyre

2. Contact patch area

In the contact patch, i.e. the area of the tyre in contact with the road surface at any given time, there is some movement of the tread blocks relative to the road which generates a ‘slip noise’. This mechanism will also be affected by the road surfacing roughness as a coarser surfacing tends to reduce the effect of slip. The tread blocks that are in the contact patch are caused to vibrate by their impacts with the asperities in the road surfacing.

Additionally as the grooves progress through the contact patch they close up, which results in the air which is ordinarily trapped within the tread grooves being compressed. The pressure fluctuations which occur due to the squeezing and releasing of the air, generate noise, this is known as 'air-pumping'. (Hayden, 1971)

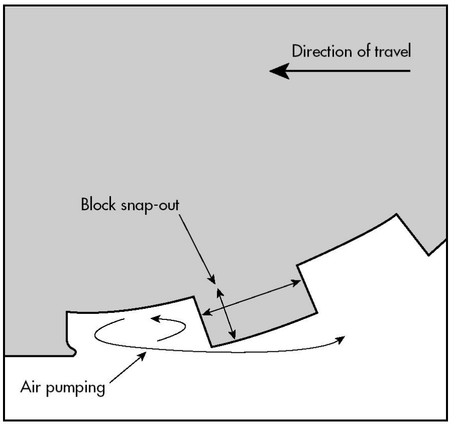


Source: (Nelson & Phillips, 1997)

Figure 3. Noise generation in the contact patch of the tyre

3. Trailing edge of the tyre

At the trailing edge, radial vibrations occur as the tread elements abruptly leave the contact patch and return to the undeflected rolling radius of the tyre. This phenomenon is known as ‘block snap-out’. The tangential forces which exist in the contact area apply significant deflections to tread blocks and it is as these forces are removed and the block is released that it has a tendency to vibrate.



Source: (Nelson & Phillips, 1997)

Figure 4. Noise generation at the trailing edge of the tyre

Additional mechanisms of noise generation which exist:

- Noise generated by the sidewalls of the tyre. The deflection in the sidewall is greatest in the region of the contact patch
- Noise created by the air cavity resonance. This is the resonance created by the air within the tyre. (Sakata and Morimura, 1990);
- Aerodynamic noise. One study states that aerodynamic noise mechanisms account for less than 10 % of the total noise. (Leagey, 1990) Another study has shown that aerodynamic noise mechanisms do not appear to be important except at very high speeds. (Hayden, 1971) Blokland, however found that with smooth road surfacings there was significant aerodynamic noise. (van Blokland, 1993)

At the front and the rear of the contact patch a ‘horn’ is formed by the tyre and road surfaces. It has been suggested that this may amplify noises produced at the front and rear of the contact patch within certain frequency bands. However, little evidence of this type of effect is cited in literature.

Frequency Analysis of Tyre/Road Interfacial Noise

Frequency spectral analysis, by Sandberg and Descornet, identified noise generation in the low-frequency range (below 1000 Hz) as being roughness-induced vibration ie block impact and block snap out. They identified noise generated in the high frequency range as being caused by air-pumping. The two processes were found to give fairly equal contributions to the overall ‘A’ weighted noise level. (Sandberg and Descornet, 1980)

Reports have shown that there is an increase of high frequency noise on a higher friction surfacing having the same macro-texture. It would appear that this means that tangential slip-stick motions in the tyre tread are also involved in the production of the high frequency noise. (Liedl and Denker, 1979) Nilsson also suggests this. (Nilsson et al., 1980) Descornet and Sandberg did not find any support for this mechanism, however they did not reject it. They prefer to explain all high frequency noise by the air-pumping or a closely related process. (Sandberg and Descornet, 1980)

INFLUENCE OF ROAD SURFACING CHARACTERISTICS ON TYRE/ROAD INTERFACIAL NOISE

During compaction of the SMA and OGA surfacings, most of the coarse aggregate particles at the surface are orientated so as to present a large face parallel to the road surface. This produces a relatively flat, planar running surface containing surface voids, i.e. a negative surface texture as shown in figure 5. The negative texture provided by both OGA and SMA means that the tyre treads are not excited to the same extent as with conventional positively textured road surfacings e.g. DGA, and so less low frequency noise is produced.

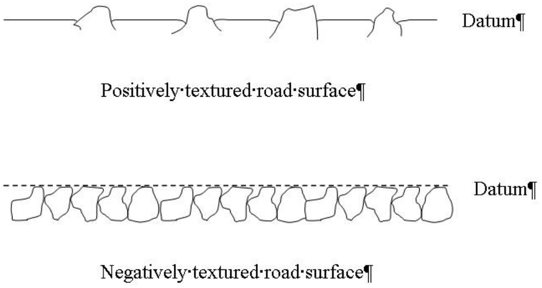


Figure 5. Positive and negative surface textures

OGA contains a high volume of interconnecting air voids, therefore rather than being compressed within the tread grooves, air is squeezed into the void spaces of the road. The negative surface texture of the SMA also provides ‘air paths’. The provision of these air-paths dissipate air trapped in the tread grooves and therefore largely prevent air-pumping occurring, hence reducing high frequency noise.

Studies have shown that the tyre/road interfacial noise level increases with increasing texture depth. However at a certain point the increase ceases, due to the tyre being unable to form a seal down to the base of the aggregate hence, reduced air-pumping. This is a similar scenario to having a negative surface texture. (Legeay, 1990)

Road traffic noise reduction is also linked with the sound absorbing qualities of OGA however this is a factor of noise propagation rather than generation and is thought to be less significant than the effects of a negative surface texture and connected air paths.

Figure 6 shows passby noise measurements made on similar stretches of road with DGA on one section and SMA on an adjacent section. It can be seen that low frequency noise levels have been reduced due to the negative surface texture and high frequency noise levels are also reduced due to the cessation of ‘air pumping’.

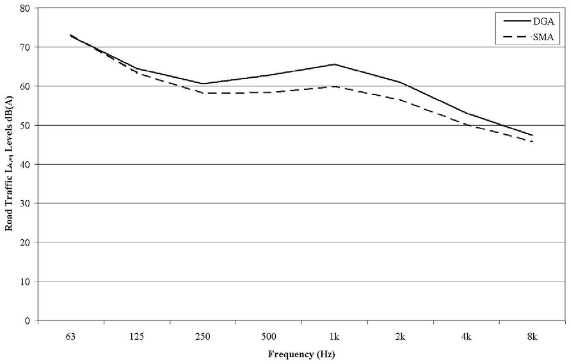


Figure 6. Road traffic noise levels of various surfacings

SKIDDING RESISTANCE MECHANISMS

Two independent mechanisms determine the grip between a road surfacing and tyres. The first of these is adhesive friction derived from molecular bonding between the tread compound and the road surfacing materials. Adhesive bonding is associated with the microtexture of the individual aggregate particles. The second mechanism, hysteretic friction, occurs as the rubber tread dissipates energy in a deformation cycle while moving over a rough surface. This mechanism is associated with the macrotexture of the road surfacing.

Adhesive friction is greatest at low speeds and falls off with increasing speed due to the time in which molecular bonds can be created being reduced. Increasing the microtexture increases adhesive friction and is therefore the main determining surface factor for good skidding resistance at low speeds.

Hysteretic friction is greatest at high speeds. On wet surfaces, the relative importance of hysteretic friction increases as the water film grows between the tyre and the road and prevents adhesive contact. In addition to generating hysteretic friction, macrotexture provides drainage paths for the water film, which then enables increased adhesive bonding to take place. (Phillips & Kinsey, 2000)

Early life skid resistance

Most if not all newly laid surfacings have a covering of binder that takes time to wear off, exposing the surface aggregate, which provides the main resistance to skidding. Heat generated by the tyres melts the coating on the aggregate and the dust, water and debris wear the coating off the surface of the aggregate. This exposes the microtexture of the aggregate, which polishes under the further action of vehicle tyres, dust, water and debris, until an equilibrium level of weathering to polishing is achieved. This equilibrium level of skid resistance will be different for various traffic volumes and aggregates.

The Materials Department of VicRoads measured the initial skid resistance of various recently surfaced roads and the conclusions are summarised below.

There are four distinct phases in the initial skid resistance life of road surfacings:

1. A preliminary stage where the skid resistance increases from a low level to a higher level. This is caused by the binder being worn off and exposing the microtexture of the aggregates in the surfacing.
2. A secondary stage where peak skid resistance occurs when all the binder has been worn off and a ‘new’ microtexture is contributing to the skid resistance.
3. A tertiary stage where skid resistance drops from the peak value to a level that appears to remain constant; and
4. A final stage, where the skid resistance is relatively constant. This is the result of the microtexture of the aggregates being worn away and the worn frictional properties of the aggregates used coming into effect (equilibrium/weathering cycle). (Parfitt, 2005)

SMA AND PURPORTED EARLY LIFE SKID RESISTANCE PROBLEMS

Until recently all skid resistance testing was performed under wet conditions. The thinking being that wet conditions would constitute the worst conditions. After several fatal crashes in the United Kingdom on the same stretch of SMA surfaced road the Highways Authority commissioned the Transport Research Laboratory (TRL) to carry out an assessment of the skid resistance effects occurring on surfacings in their early life. The work included an initial investigation of the effect of speed on both wet and dry skid resistance on new Stone Mastic Asphalt surfacings, followed by further phases in which a more limited range of measurements were made on a greater number of sites in order to extend the study to a wider range of surfacing types of different ages, roads and traffic conditions. The main conclusions are summarized below. (Roe and Lagarde-Forest, 2005)

- Low speed skid resistance was found to be high under wet conditions even though the microtexture was coated; This suggests that a different adhesive mechanism than aforementioned was occurring.
- Low speed skid resistance under dry conditions was found to be similar to that under wet conditions, approximately 20% lower than the levels obtained on older surfacings from which the binder film has worn off. Under dry conditions bitumen can melt as a result of the heat generated by braking in the tyre contact area causing a reduction in skid resistance compared with a surfacing with exposed aggregate, this is known as bitu-planing.
- High speed skid resistance under dry conditions is approximately 30-40% lower than the levels obtained on older surfacings from which the binder film has worn off. The resistance is nonetheless much higher than that under wet conditions.
- Wet skid resistance decreases with increasing speed as expected, due to the microtexture not being able to make contact with the tyre.
- The effects can be observed on any new surfacing, but the length of time for which they persist will vary depending upon local conditions and traffic levels. Typically, most effects have disappeared after 6 months but they may persist longer and have been observed for up to 18 months on surfacings with light traffic and thicker binder films.

The use of a fibre stabiliser, required to keep the SMA mix homogenous as mentioned earlier in this paper, produces a thicker binder film on the aggregate which affects the rate at which trafficking can remove the binder film and expose the aggregate. For this reason the initial phase of early skid resistance of SMA surfacings may be prolonged relative to other road surfacings. (Parfitt, 2005)

Another study identified several causes of the lowered early life skid resistance and dry bitu-planing:

- Badly designed or manufactured mix – Excess or incorrectly formulated binder composition may prevent the aggregate from becoming exposed under normal trafficking conditions. Insufficient surface voids and/or excess bitumen in the mix may become smeared by trafficking and cause the binder to in-fill the voids leading to the creation of a bitumen rich slippery surface.
- Inadequately controlled laying - Trafficking by rubber tyred vehicles before the SMA surfacing has sufficiently cooled i.e. to below 40°C, may cause the binder to be flushed to the surface again preventing the aggregate from becoming exposed. (Woodward et al., 2005)

Skid resistance tests performed by the Irish National Roads Authority (NRA) showed that skid resistance in dry conditions on some SMA surfacing was similar to the results for wet conditions, corroborating the TRL report findings. Consequently the NRA has restricted the use of SMA to roads with a 50 km/h speed limit, and has taken remedial action on roads with existing SMA surfacing such as the use of chip sealing. (Fleming, 2002)

Following fatal crashes on the Bruce Highway at Federal near Gympie, the community questioned the use of SMA on

Queensland roads. The Queensland Department of Main Roads (DMR) commissioned an independent investigation into the use of SMA. The review examined all 537 Main Roads' SMA sites. It found that there had been a 33 % reduction in fatalities on these roads when comparing crash rates before and after the laying of SMA. The study found that SMA is an appropriate surfacing and the use of SMA does not show any inherent safety issues. Nonetheless the investigation did conclude that SMA requires more attention to detail when being mixed, transported and laid in the field than traditional surfacings. It is believed that once the expertise and capability is obtained the surfacing is no more difficult to mix and lay than other surfacing materials. To minimize the likelihood of early life skid resistance safety issues arising with SMA surfacings the investigation recommended that the Department of Main Roads develop a performance based specification for SMA and a scheme to pre-qualify asphalt contractors on their mix, mixing procedure and layering procedure. Other recommendations included an increased level of auditing on the materials, components, manufacturing processes, production mix approval and the laying procedure for SMA. It was also recommended that the Department of Main Roads implement a 12 month warranty period for all surfacings. (Troutbeck & Kennedy, 2005)

CONCLUSIONS

1. SMA and OGA surfacings provide a significant reduction (approximately 3 dB(A)) in tyre/road interfacial noise levels compared with DGA.
2. The reduction of tyre/road interfacial noise is due to the negative surface texture reducing vibrations in the tyre and connected air paths reducing 'air pumping' noise.
3. Several fatal crashes have been reported in Australia, the United Kingdom and Ireland with multiple occurrences on the same stretches of SMA surfaced roads.
4. Low skid resistance performance was identified on these particular sections of SMA surfaced roads. A number of causes for the low skid resistance were ascertained including badly designed or manufactured mixes and inadequately controlled laying procedures all of which can contribute to a significantly longer period where aggregate is not exposed compromising the skid resistance performance of the surfacing.
5. In-depth investigations have concluded that SMA is an appropriate road surfacing, not showing any inherent safety issues. SMA does require more attention to detail when being mixed, transported and laid in the field than traditional surfacings. However, once the expertise and capability is obtained the surfacing is no more difficult to mix and lay than other surfacing materials. A pre-qualification scheme for contractors' mixes, missing and laying procedures may help minimize problems.

REFERENCES

Fleming, D 2002, 'Slippery when wet and dry', New Civil Engineer, 7 February 2002

Hayden, R.E. 1971, 'Roadside noise from the interaction of a rolling tire with the road surface', Proceedings of the Purdue Noise Control Conference

Legeay, F.J. 1990, 'Macro-texture and low frequency tyre/road noise correlation', International tyre/road noise conference

Liedl, W., Denker, D. 1979, 'The influence of road and tread pattern on tire noise and skid resistance', Proceedings of the International Tire Conference, Stockholm

Nelson, P.M., Phillips, S.M. 1997, 'Quieter Road Surfaces', TRL Annual Review 1997, Transport and Road Research Laboratories, Crowthorne

Nilsson, N.A., Bennerhult, O., Soderqvist, P. 1980, 'External tire/road noise; its generation and reduction', Inter-noise '80, Miami

Parfitt, C. 2005, 'Road Safety and the Initial Skid Resistance of Various Surface Treatments', Materials Technology Department, VicRoads

Phillips, S., Kinsey, P. 2000, 'Advances in identifying road surface characteristics associated with noise and skidding performance', PIARC Surface Characteristics 2000, Nantes, Transport and Road Research Laboratory, Crowthorne

Roe, P.G., Lagarde-Forest, R. 2005, 'The early life skid resistance of asphalt surfaces', Transport Research Laboratories, Crowthorne

Sakata, T., Morimura, H.I. 1990, 'Effects of tire cavity resonance on vehicle road noise', Tire Science and Technology, TSTCA, Vol. 18(2) pp. 68-79

Sandberg, U. and Descornet, G. 1980, 'Road Surface influence on tire/road noise – Parts I & II', Inter-noise '80, Miami

'Sound Effects' 1996, New Civil Engineer: Roads Supplement

Troutbeck, R., Kennedy, C. 2005, 'Review of the use of Stone Mastic Asphalt (SMA) surfacings by the Queensland Department of Main Roads', Queensland University of Technology

van Blokland, G.J. 1993, 'The effect of road surface properties on rolling noise levels of different tyres' Internoise'93, Leuven, Belgium

von Meier, A., 1993, 'Europe's Environment 1993 – Noise Pollution' DG XI Task Force European Environment Agency Brussels, Belgium

Walker, J.C. 1981, 'Noise generated at the tyre-road interface', PhD Thesis, University of Aston

Woodward, WDH., Woodside, A.R., Jellie, J.H. 2005 'Early and mid life SMA skid resistance', International Conference Skid Resistance, Christchurch, New Zealand