Bituplaning: The Truth and the Friction concerning Dry Friction and New Bituminous Road Surfaces

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ABSTRACT

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A frictional phenomenon presently observable on some new negative textured road surfaces in dry conditions, challenges the typical understanding that the frictional properties of any given road surface in the dry are generally superior to those of the same surface in the wet.

Evidence of reduced dry road friction, caused by the presence of a non-water layer between tyre and road surface aggregate on an otherwise uncontaminated surface, has been documented as early as the 1940s (Zipkes, 1944) and the principles of determining dry road friction from simulated emergency braking, using a braking tests, have been used in courts of law for over sixty years (New York State City Magistrates, 1940). Low dry friction on uncontaminated road surfaces has been measured in the UK on both traditional road surfacing and the more modern negative textured road surfaces, in the latter case no evidence exists to link this to any fatal or near fatal crashes in the UK.

A combination of empirical testing combined with the statistical analysis of police deceleration tests have added to the understanding of, but not directly identified a single mechanism responsible for, the generation of low dry friction on negative textured surfaces – a phenomenon termed 'bituplaning' by some individuals owing to its similarity to aquaplaning/hydroplaning.
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INTRODUCTION

This document summarises the key findings of a PhD study undertaken by the author whilst a post-graduate researcher in the Transportation Research Group (TRG) of the Dept of Civil Engineering and the Built Environment of the University of Southampton (supervisor Dr N B Hounsell). The Author is grateful for bursary funding from the Rees Jeffrey Road Fund and additional sponsorship from The Highways Agency. The PhD study continued elements of a review of the tyre/road interface undertaken by the Author for the AA Foundation and the County Surveyors Society [3]. Presentations made [4-7] as the work progressed assisted in securing additional data sources and assistance.

Typically, highway engineers had assumed that uncontaminated road surfaces deliver higher levels of friction in the dry than when they are wet, thus the development of road surface friction measurement techniques commonly include only a limited number of observations on measuring dry friction before abandoning such measurements with the assumption that only wet friction was likely to be a problem in the future [8, 9].

Attempts to measure dry friction using devices designed to measure wet road friction have commonly resulted in failure [10], the only devices appropriate for the measurement of both dry and dry road friction are either deceleration recorders mounted in ordinary road vehicles or testing devices which use instrumented rolling tyres braked for testing (e.g. The Dynatest Pavement Friction Tester - PFT). Any fatal or near-fatal road traffic collision in the UK is likely to be subject to a detailed and professional investigation which may well include surface testing to determine frictional characteristics, whether in the wet or the dry.

Road traffic accident collision investigators are responsible for recording any relevant characteristics of a road surface at the time of a collision. Since collisions are not uncommon in the dry, the investigation of these events gives collision investigators an understanding of dry road friction on a par with the highway engineers' knowledge of the wet road.

Without easy access to dry road friction measurement devices, the highway engineer is unlikely to understand how dry road friction is measured or to know the levels of dry road friction considered "typical". With a wealth of understanding of the measurement of wet road friction, there is also a tendency for these same engineers to assume good wet grip must imply a good dry grip, an assumption generally based in fact. This work describes one particular exception to this assumption, how it manifests itself and how it may be quantified.

THE PHENOMENON OF LOW DRY ROAD FRICTION

Before the arrival of negative textured road surfaces (NTS, such as porous asphalt, generic stone mastic/matrix asphalt (SMA) and in the UK, BBA/HAPAS thin surfacing), potential had already existed on positive textured surfaces (PTS) for a layer of bituminous binder material to interfere in the direct interaction of the tyre with the road surfacing aggregates.

The literature review identified investigations as early as the 1940's (Zipkes, 1944) which were undertaken to quantify the influence on dry road friction of a non-aqueous layer between tyre and road surface aggregate, just as the presence of water between the tyre and the road surfacing aggregate particles had been shown to make roads slippery in the wet..

In the UK in the 1980's, a multiple fatality on the M4 motorway was investigated and greatly reduced dry road friction (below that measured in the wet) was measured. This caused greatly extended braking distances that played a key role in the loss of life, unfortunately sub-standard crash barriers also were contributory and this element of the investigation became the focus of most press coverage (Shelshear, 1986b, Shelshear, 1986a, Shelshear, 1986?-a). The investigation strongly suggested that an excess of bitumen on the pre-coated chipping used on site were the cause of the low dry friction (Shelshear, 1986b, Shelshear, 1993, Shelshear, 2005). Acceptable wet skidding performance was also proven (Shelshear, 1986?-b).

In the Netherlands in the early 1990s, increased emergency braking distances were observed on new porous asphalts (ZOAB) when ABS brakes were disengaged and wheels could then lock. Considerable research was undertaken to establish the acceptable levels of dry friction below which warning signs had to be erected. Despite detailed studies, no reliable or cost-effective method of achieving an early increase in the dry friction was found (Van Der Zwan et al., 1990, Jutte and Siskens, 1997, van der Zwan et al., 1997, Swart, 1997).

In the UK, in the early 2000's, two fatal collisions on new Stone Mastic Asphalt (SMA) occurred in Derbyshire where unacceptably low levels of dry friction were measured, the subsequent police investigations failed to link this low dry friction to the crash outcomes (Harris (Constable), 2001, Allen (Constable 1357), 2001), however the association of low dry friction, a new type of road surface and several fatalities provided a rich picking ground for the press (Fleming, 2002, Khan, 2003, Anon, 2003, Bird and Scott, 1936, Chilcott-Moore and Gregory, 2005, Anon, 2005, Morgan, 2005, Farrell, 2005). As the Netherlands research was confined to Porous Asphalts, little if any reference was made to it, despite the very relevant methodology it had already established for the investigation of low dry friction and the combination of regular dry friction measurement and the use of warning signs.

THE PHD RESEARCH

Within a limited number of pages, it is only possible to provide the briefest of summaries of the extensive work undertaken during the period 2003-2006.

In addition to a detailed literature review providing the details above, the work undertaken in the PhD study aimed to establish the extent of the low dry friction phenomenon via the use of Skidman (Turnkey Instruments Ltd, 1994?, Logan, 2004b, Logan, 2004a, Logan, n.d.) decelerometer measurements made at fatal or near accident scenes (this data was readily accessible and avoided the significant costs and complex logistics involved in undertaking bespoke road testing).

The Skidman data was statistically analysed, and compared against typical levels of dry friction, to establish the significance of surface type (negative texture or positive texture) and braking system (ABS or No ABS) on levels of deceleration in simulated emergency braking manoeuvres.

Other elements of the study aimed to investigate the conditions at the tyre/road interface during emergency braking, relating them to the effect of laboratory tests on bituminous materials which aimed to reproduce some of the same conditions.

DECELERATION DATA COLLECTION AND PROCESSING

The main source of deceleration data for the study was obtained by downloading Skidman devices belonging to a number of English police forces. The Skidman device is usually used to deliver a paper printout summarising average and maximum deceleration following a simulated emergency stop “skid test”. These summary values are then used in reconstruction calculations (Derbyshire Constabulary Road Policing Support Unit, 2005)). An MS-DOS application (SIMRET) was used in Windows 98SE to download the momentary decelerations recorded during each event (40hz data) then these data streams were combined using a Microsoft Excel macro to produce a large spreadsheet. Key points in the individual skid test profiles were visually identified, using another macro driven process, to generate summary data points as input into subsequent statistical analyses.

SKIDMAN DATA ANALYSIS

As the data collected was “real” field data, rather than the result of computer simulations or controlled laboratory measurements, some variation was likely to be seen, however the trends in average deceleration with respect to braking state (ABS No ABS) and surface type (NTS & PTS) were common between forces.

Significant differences were seen for average deceleration between ABS and No ABS on Dry NTS surfaces and for the No ABS performance of dry NTS and PTS surfaces (see Table 1). With ABS, Dry NTS surfaces offered significantly improved average deceleration than PTS surfaces. Peak deceleration performance showed no significant effect of surface type.

Average Deceleration DRY SURFACES				
Sig. diff.@ ≥99% ?	**ABS NEG**	**ABS POS**	**No ABS NEG**	**No ABS POS**
ABS NEG	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**ABS Higher**	**NO SIG. DIFF.**
ABS POS	**NEG Higher**	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**ABS Higher**
No ABS NEG	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**No Sig. Diff.**	**NO SIG. DIFF.**
No ABS POS	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**NEG Lower**	**NO SIG. DIFF.**

Peak Deceleration DRY SURFACES				
Sig. diff.@ ≥99% ?	**ABS NEG**	**ABS POS**	**No ABS NEG**	**No ABS POS**
ABS NEG	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**ABS Lower**	**NO SIG. DIFF.**
ABS POS	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**ABS Lower**
No ABS NEG	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**NO SIG. DIFF.**
No ABS POS	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**NO SIG. DIFF.**	**NO SIG. DIFF.**

Table 1 - Summary of T Test results and significance tests on DRY ROAD tests

TYPICAL LEVELS OF DRY FRICTION

Before the measured dry friction performance could be deemed to be sub-standard or “less than typical”, it was important to establish what was actually considered “typical” dry friction, two sources were used: feedback from professional collision investigators and the technical literature.

A questionnaire was completed by members of a collision investigators forum as to their understanding of what constituted typical dry road friction, the results supported the typical values for dry road friction in the literature (Ebert, 1989, Wallingford et al., 1990, Goudie et al., 2000, Varat et al., 2003, Manderson, 1992, Manderson and Rudram, 1993, Bailey, 2000, Lambourn, 2004) which in turn supported the levels of dry friction considered typical by Shelshear (Shelshear, 1993) in the investigation of the M4 crash and later in Derbyshire.

Additional parameters such as the ratio of peak to sliding No ABS deceleration have also been studied (Ebert, 1989) providing additional benchmarks for typical performance.

Part of the PhD study included the collation of measurements from a test exercise undertaken by North Wales Police using impounded and pool vehicles (these included a Ford Galaxy, a Porsche 911, and a Ford Escort diesel van and included both ABS and No ABS vehicles).

The magnitudes of the differences observed between the typical average locked wheel (No ABS), and typical average ABS simulated emergency braking deceleration were established and agreed well with the typical values measured in the literature.
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LOW DRY FRICTION AND RISK

By virtue of the use of police data in the study, the Author was able to interview a number of collision investigators in order to establish if the low dry friction phenomenon had been proven to have resulted in a fatality or near-fatality, despite extended dialogues, no evidence was found.

A single incident in the dry, in Derbyshire, involving a pedestrian fatality on an SMA surface, identified low dry friction and may well have satisfied all the requirements had it not been for a lack of key forensic evidence regarding pedestrian movements (Allen (1357), 2002).

It is important to observe that slight injury and serious injury accidents are typically not professionally investigated in the UK, nor could civil cases settled out of court be considered owing to lack of disclosure.

LOW DRY FRICTION OVER TIME

With the assistance of Derbyshire Police, Dorset Police and Derbyshire County Council it was possible to undertake, or obtain data from, a limited number of deceleration measurements over time, to establish how the levels of dry friction may improve with trafficking. The datasets secured should not be considered comprehensive and the findings did not provide a viable model for the measured increase in dry friction with trafficking and/or environmental exposure. They all showed an upward trend in dry friction with time of exposure/cumulative traffic.

Improvement in dry friction over time to a high static maximum had already been observed in The Netherlands, this dry frictional behaviour over time contrasts with the classic model of wet friction where a high initial value decreases over time to a lower dynamic wet friction equilibrium.

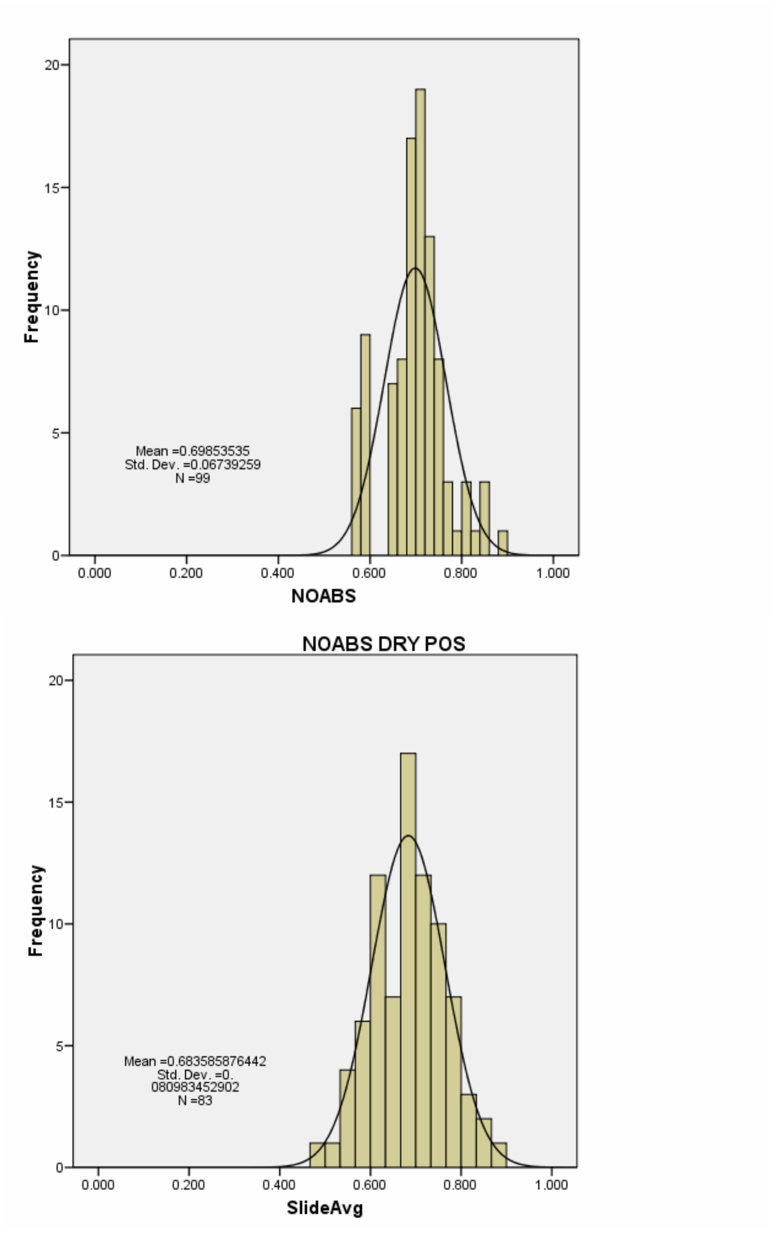

Figure 1 - Top: North Wales HRA (single surface) NOABS DRY POS versus Bottom: Study Remaining PhD Database NOABS DRY POS

MITIGATING LOW DRY FRICTION

Considerable research has been undertaken in The Netherlands to identify a cost-effective and reliable method to deliver acceptable in-service dry friction on brand new porous asphalt, since as little of this material performs well in the dry until at least 4 months old.

SMA laid in Germany was already being gritted to improve initial skidding resistance (Nunn, 1994, Bellin, 1997, Richardson, 1999) when SMA materials were first used in the UK, however mixes used in the UK may be atypical of their earlier German origins. The discussion of proprietary methods in the UK for improving the frictional properties of negative textured surfaces is beyond the scope of this document; however the use of a layer of Bomag applied fine grit to new SMA materials in Devon and elsewhere has been shown, via decelerometer (Skidman) testing, to improve initial dry and wet friction.

It is likely that the use of “gritting” on newly applied UK BBA/HAPAS approved materials would compromise their certification/warranty: any post-installation treatments to address early life frictional issues would have therefore need to be integrated into this certification.

Issues of low wet friction on new negative textured road surfaces were also beyond the scope of this study, however these have been documented (Bastow et al., 2005) as wet friction measurements can easily be undertaken and the results compared against existing wet friction standards (Henry, 2000)

LOW DRY FRICTION AND ABS BRAKING

The deceleration time-series downloaded from police Skidman devices, measurements made during UK test days on new NTS materials in the UK, and results from the Christchurch correlation exercise forming part of the 2004 International Conference were studied and momentary periods of reduced deceleration during ABS tests were observed on very new surfaces. These minima we similar in magnitude to the levels observed during No ABS tests.

Work in The Netherlands (Fafié, 2004) suggested that ABS braking would mitigate the potential for low dry friction to occur, the evidence above combined with photographic evidence contradict this: conspicuous “dashes” have been seen following ABS skid tests on NTS (see Figure 2).

LOW DRY FRICTION, HIGH SHEAR AND DE-OILING

One model proposed to explain the generation of low dry friction was melting of the road surface, as a result of heat transfer between tyre and road surfaces as braking progressed. Simplistic theoretical modelling undertaken in The Netherlands (Jutte and Siskens, 1997) suggesting a tyre/road interface temperature of 450°c during a locked wheel (No ABS) braking event was not supported by the measurements made directly behind a sliding tyre using thermal imaging technology.

Figure 2 - Left: ABS “dashes” observed on an NTS in Dorset following ABS testing (No ABS skid marks in background) Right: Semi continuous ABS “dashes” observed on an NTS in Derbyshire following testing

Figure 3 - Left: Oily deposit observed following No ABS test on SMA in Devon, Right: Oily deposit and bitumen observed following No ABS test on SMA in Dorset

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One alternative mechanism which may be responsible for the generation of the low could be the high levels of shear the binder/mastic film is exposed to during sliding (a peak shear of 13m/sec at 50kph). These high levels of shear cannot easily be reproduced in the laboratory, however Dynamic shear rheometry tests undertaken at 100°c on binder samples (not the mastic layer recovered from the material) by VDOT (Virginia Dept. of Transportation) identified levels of shear induced viscosity more typical of liquid motor oil than of in-service bituminous materials – this result may in some way link the measured deceleration performance of oil saturated surfaces (Lambourn and Viner, 2006) and the deceleration observed in No ABS tests on new NTS surfaces where oily patches were observed post-test (see Figure 3)

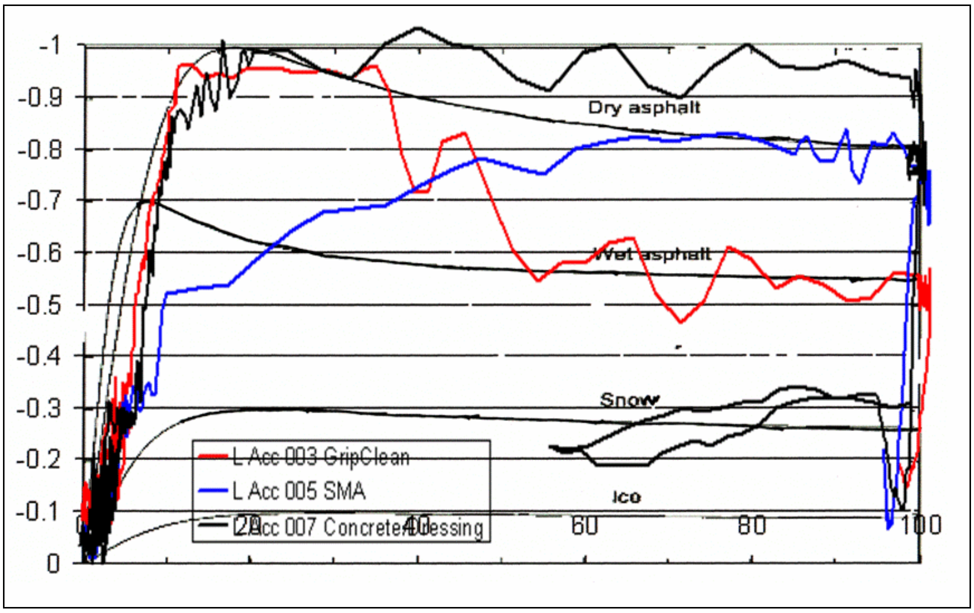

Figure 4 - Grip versus Slip percentage for DRY tack coat (red), SMA (blue), and Concrete (black) versus typical grip slip curves

GRIP/SLIP CURVES

Classic grip versus slip characteristics have evolved over time to represent the performance of dry, wet and icy surfaces. With the generation of momentary periods of low friction during ABS braking it was important to try to establish how the grip/slip behaviour of new NTS materials could challenge the establish grip/slip model for traditional (PTS) dry roads

Using wheel rotation and GPS equipment kindly loaned by Datron (UK), it was possible to determine limited grip slip curves for a new NTS (6mm latex modified un-gritted SMA,), a control dry concrete surface and a bitumen bond coat.

The typical grip/slip curves for the new un-gritted SMA showed behaviour more akin to that of a wet surface than a dry one (Figure 4).

NTS SURFACING AND THE EFFECT OF BINDER FILM ON CRITICAL SPEED

The level of locked wheel surface friction available to a vehicle has been shown to influence the critical speed above which a bend cannot be safely negotiated, the measurement of surface friction at a crash scene may be used to establish the speed at which a vehicle left such critical speed marks (Smith, 1991, Greatrix, 2002, Brach, 2005).

A limited investigation of the influence of the SMA binder/mastic film on critical speed was undertaken by the Metropolitan Police with the Authors input. This work only confirmed that one particular worn SMA showed a similar critical speed behaviour to a Hot Rolled Asphalt– A new (and binder-rich) SMA is yet to be tested in the same manner.

IMAGING THE TYRE/ROAD INTERFACE – HRA / NTS BITUPLANING AND TEMPERATURE

Using state-of-the-art high speed (1000 fps) and infra-red imaging it was possible to capture the bituplaning event in both the visual light and thermal spectrum.

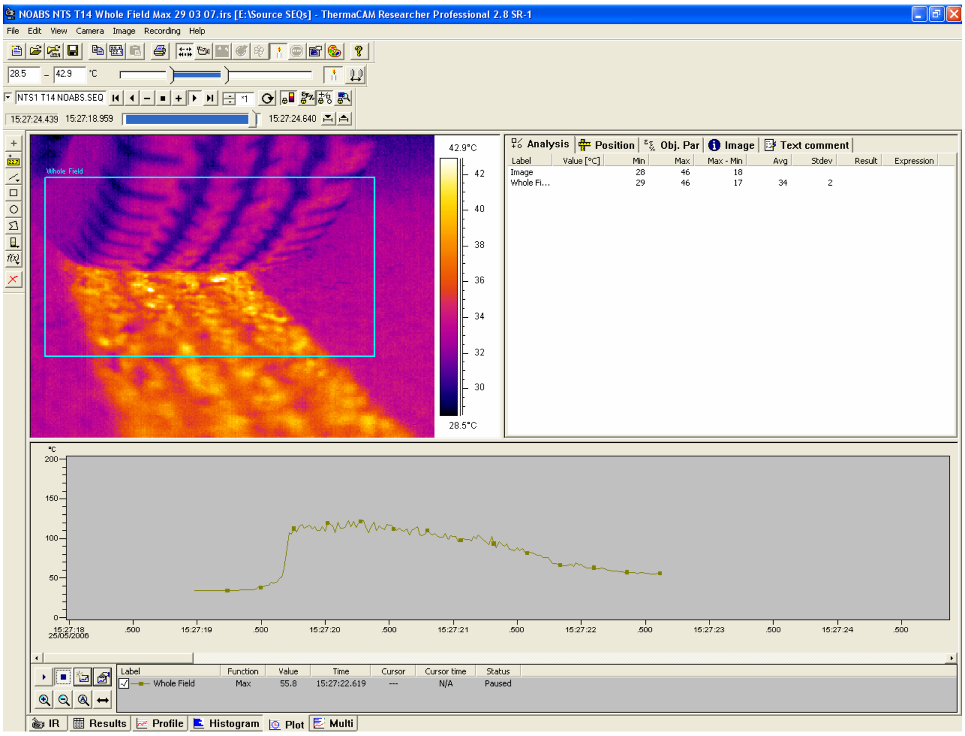

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Figure 5 - FLIR Researcher Software derived No ABS thermal MAXIMA No ABS NTS

Sophisticated thermal and image analysis software provided a moment-by-moment view of the bituplaning (low dry friction) event as visual images (see Figure 5) and a stream of point temperatures from within the visual field of the camera. This analysis showed that higher peak temperatures were achieved between tyre and road surface when the same No ABS tests were undertaken on a worn PTS surface than on a new NTS surface (see **Error! Reference source not found.**). This analysis supported the findings of Zipkes (Zipkes, 1944) sixty years earlier.

KEY CONCLUSIONS DRAWN FROM THE RESEARCH

The following section details the conclusions drawn from the whole PhD study and refers to certain areas of activity which may not have been comprehensively detailed in this document.

EMERGENCY BRAKING ON NTS AND PTS

Dry NTS surfaces can deliver levels of dry friction BELOW the level of dry friction considered TYPICAL by collision investigation professionals and described as typical in the literature.

Levels of No ABS dry friction similar to those measured when skid testing on diesel or petrol contaminated surfaces can be delivered on DRY NTS.

DRY NTS surfaces have been seen to behave significantly WORSE during No ABS emergency braking in the DRY than DRY PTS surfaces.

ABS braking may only partially mitigate the bituplaning effect.

DRY NTS surfaces behave significantly BETTER during ABS emergency braking than DRY PTS surfaces.

There is a greater difference between ABS and No ABS average friction for DRY NTS than for DRY PTS surfaces.

The ratio of sliding over peak friction is numerically smaller for DRY NTS surfaces than for DRY PTS surfaces in No ABS tests (i.e. there is a greater difference between sliding and peak friction for DRY NTS surfaces).

IMAGING/MEASURING BITUPLANING AND POSSIBLE BITUPLANING MECHANISMS

The behaviour of the tyre can now be observed during No ABS DRY NTS testing and such observations suggest that NTS macrotextures may generate fundamentally different frictional behaviours during emergency braking than for more traditional textures, potentially delivering reduced hysteresis derived friction.

Melting is not necessarily the only mechanism responsible for the low dry friction as momentary low levels of dry friction have been seen during ABS tests.

Oil exudation may provide a mechanism for the generation of low levels of sliding friction.

Oil exudation may combine with low adhesion and low hysteresis to produce the bituplaning effect; however, more tests are required of surfaces manufactured with binders of known exudation potential.

DRY FRICTION OVER TIME

Existing guidance on the duration of time during which low dry friction may be an issue, may be grossly underestimated if traffic levels are low.

LOW DRY FRICTION AND ACCIDENTS

Bituplaning may not have been identified as having a significant role in collisions owing to the insufficient number of non-fatal crashes investigated by trained collision investigation professionals.

Proper investigation of more non-fatal crashes may reveal the true role of bituplaning in collisions.

BITUPLANING AND CRITICAL SPEED

The binder film on new NTS surfaces could (unless proven otherwise) result in a change in the maximum safe speed at which a vehicle can safely travel round a bend.

The bituplaning effect may not influence critical speed on curves where near-lock or locked wheel conditions are not prevalent, however this remains unproven.

ADVICE AND FURTHER WORK RESULTING FROM THE RESEARCH

Respect the fact all new bituminous surfaces may have reduced dry friction when braked on in an emergency by a vehicle without ABS.

The wide use of NTS in the UK may require changes in driver training to make them aware of the risk of bituplaning if their vehicle is NOT ABS equipped.

More non-fatal crashes require professional investigation to understand better the manifestation of bituplaning in crashes and its contribution to crash outcome.

A link needs to be either established or discredited between smoother quieter roads and higher road speeds.

Highway engineers should understand the changes over time in their NTS materials in response to the effect of cumulative traffic and climatic effects on the bituminous layers on NTS.

More work is needed to study the influence of DRY NTS friction on critical speed behaviour of these surfaces.

Oil exudation capability should be studied in relationship to bituplaning potential.

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