

EFFECTS OF VERY LARGE INNOVATIVE HEAVY VEHICLE COMBINATIONS ON PAVEMENT SURFACES

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Abstract

This paper describes progress made under a research project which aims to quantify the relationship between pavement surface wear and heavy vehicle tyre forces. The tyre forces applied to various pavement surface types by new configurations and loadings of freight vehicles are often not known. The paper discusses how this need was addressed by commissioning new equipment that can apply tyre forces and slips to a pavement surface at full scale, representing any single or dual tyre from any steer, drive or trailer wheel from any heavy vehicle combination. A new technique used to measure and quantify pavement surface wear is also described which provides an improved understanding of the failure modes present and how these are linked to tyre contact patch forces.

Keywords: Pavement Surface Wear, Tyre Test Rig, Innovative Heavy Vehicles, Surface Topography, Line Scanning Laser

1. Introduction

One barrier to road access for very large innovative heavy vehicle combinations is a negative perception from road owners regarding pavement surface wear. This perception generally exists because the tyre forces applied to pavement surface types by new configurations and loadings of freight vehicles are often not known. In order to address this issue, a research project which aims to quantify the relationship between pavement surface wear and heavy vehicle tyre forces is under way.

It is hoped that these tyre forces can be predicted for new heavy vehicle combinations before they are assembled. This may allow appropriate pavement surface selection for specific sites where manoeuvres result in high shear stresses, such as rural T-junctions, climbing lanes, areas of traffic stopping, starting and channelisation. There also exists a requirement to improve the understanding of failure modes over typical surfacing life cycles that are particular to the pavement surfacing layer, as distinct from the structural layers, beyond simple gross texture quantification and qualitative observation. Failure modes of surfacings are often horizontal shear-stress induced rather than vertical-load induced, and include aggregate particle plucking, binder shearing and bleeding.

Eventually, models will be developed to predict horizontal loads applied by innovative trucks and to predict the resulting pavement surface wear. This information will not only allow road owners to take appropriate action to accommodate new innovative heavy vehicle combinations on their networks but is also necessary to support the development of incremental pricing and mass distance charging of heavy vehicles.

2. Research Method

In order to understand the tyre forces applied to pavement surfaces by new configurations and loadings of freight vehicles, it was proposed to determine the manoeuvre geometry and vehicle characteristics, then apply the actual operating conditions of any chosen critical wheel to an instrumented and actuated tyre rig test wheel described in Section 2.1. The horizontal tyre forces that result from these operating conditions can then be measured and the resulting pavement surface wear evaluated. Although beyond the scope of this paper, the tyre force approach involves calculations which combine axle group static loads, driveline characteristics, suspension geometry and stiffnesses, with 3D manoeuvre geometry. This allows vertical loads, torques, slip and camber angles to be calculated. Once these operating conditions are applied to the tyre rig test wheel the resulting horizontal tyre forces can be measured.

When attempting to gain an improved understanding of the failure mechanisms that are particular to the pavement surfacing layer, it was deemed necessary to determine if these failure mechanisms are present under low-cycle (< 10) loading conditions. Significant literature reviews and consultation with practitioners were undertaken which strongly suggested this is the case. A recent field trial was completed to determine if significant pavement surface wear could occur due to realistic tyre loads after only a few cycles and determine if the equipment and techniques developed during the current project are able to accurately detect this wear.

2.1 Equipment

A review of both laboratory-based and mobile tyre force and/or surface wear measurement rigs concluded that in order to understand pavement surface wear mechanisms, it is important to apply tyre forces and slips at full scale with realistic tyre/pavement contact and temperatures. The review of existing technologies suggested only mobile tyre test rigs lend themselves to achieving the aim of applying and quantifying the tyre forces required to achieve realistic pavement surface layer wear.

The tyre force and surface wear mobile rig developed (Figure 1) can replicate the forces and therefore stresses applied to the pavement surface by any single or dual tyre from any steer, drive or trailer wheel from any heavy vehicle combination undertaking any manoeuvre in an accurate and most importantly, repeatable manner. If these stresses can be accurately applied and the resulting surface wear accurately measured, a link between the two can be drawn that currently does not exist in the literature.



Figure 1 – Tyre force and surface wear mobile rig

A survey of existing pavement surface wear measurement techniques suggested that few have the capacity to identify and track the movements of individual aggregate particles with a high degree of precision. A surface topography laser rig (Figure 2) was designed and constructed comprising a traversing laser device that can scan the surface and generate data points that can then be imported to, and manipulated by, computer software. This allows accurate measurement of surface wear, especially under aggressive low-cycle loading conditions.



Figure 2 – Surface topography laser rig

2.2 Procedure

The tyre rig was used to simulate a B-double combination with unladen lead trailer and fully-laden tag-trailer starting from rest on a steep grade. The operating conditions of a single drive tyre from this vehicle were applied to a lightly-trafficked hot mix asphalt pavement surface. As previously mentioned, the detailed tyre operating conditions calculation, application and measurement approach is beyond the scope of this paper. Three survey spikes were driven into the surface just outside the area to be trafficked (Figure 3), to give a relative reference between the measurements of the lightly-trafficked 3D surface coordinates and the post-wear coordinates.



Figure 3 – Test tyre positioned on test section

The single test tyre was positioned to pass through the test section, within 20 mm of the survey spikes, in a location similar to that shown in Figure 3. The test tyre was a drive tread pattern with a vertical load of 1.2 tonnes, inflated to the manufacturer's recommended inflation pressure for the given vertical load, 90 PSI.

The tyre operating conditions resulted in gross slippage of the contact patch and after only a single application of torque and load, hence horizontal stress, noticeable pavement surface wear was present and as a result no further load cycles were applied. Although the simulation of this manoeuvre involved a straight path, the tyre rig allows for small test surfaces to be utilised as in the case of a turning manoeuvre rather than a curved path with straight wheel; instead, the test wheel is progressively steered with a straight path, replicating actual operating conditions almost identically.

The surface topography laser was used to measure the test section lightly-trafficked 3D surface coordinates and post-wear coordinates. The geometry of the three survey spikes, present in each scan, were then used to rotate and translate each set of scanned coordinates, so the difference between them could be analysed, without having to precisely position the laser rig in exactly the same position before and after the surface wear event.

3. Results and Discussion

The observation that only a single load cycle was required to cause obvious pavement surface wear supports anecdotal evidence that failure mechanisms particular to the pavement surfacing layer can be present under low-cycle (< 10) loading conditions. In addition to the new surface wear measurement and analysis technique, a common approach of analysing photographs was also undertaken. Figure 4 shows the lightly-trafficked and post-wear surface characteristics.



Figure 4 – Lightly-trafficked (left) and post-wear (right) hot mix asphalt surface

It was observed that multiple aggregate particles were plucked from the binder by the combination of horizontal and vertical stress applied to the pavement surface by the test tyre. The majority of these were near the tyre tread shoulder, suggesting this is a region of particularly high relative stress. Many other aggregate particles were sheared relative to their initial position and significant shearing of the binder over the top of the remaining aggregate particles was evident.

The lightly-trafficked and post-wear laser scans can be seen in Figure 5 and Figure 6 respectively (coordinates are mm).

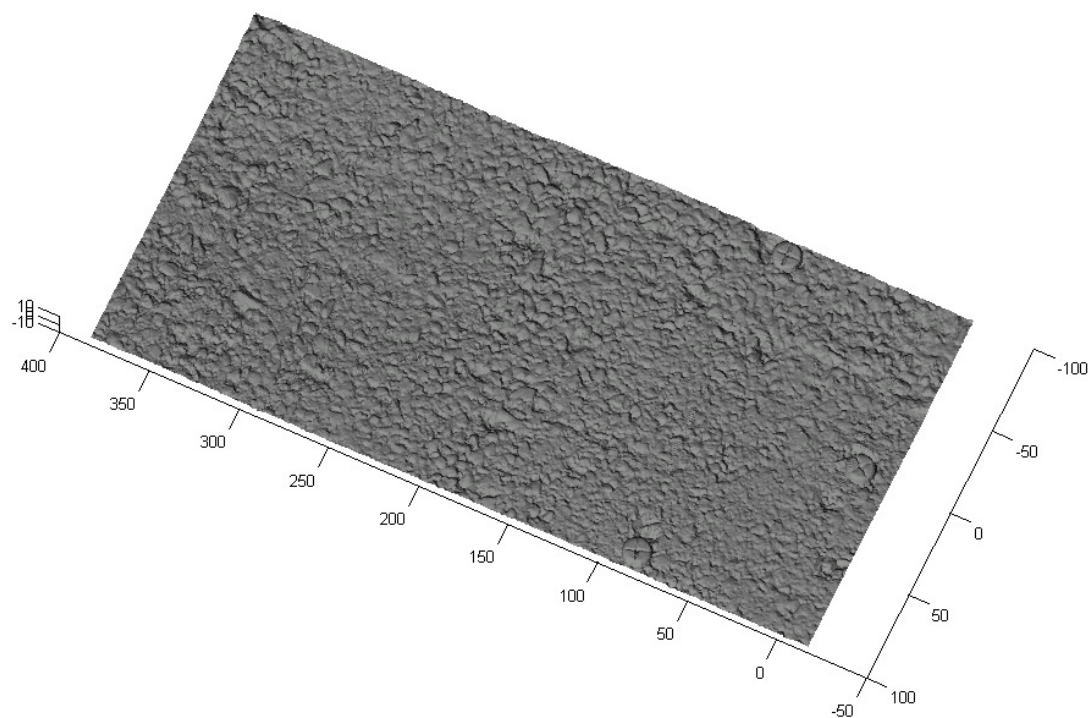


Figure 5 – Lightly-trafficked hot mix asphalt pavement surface before testing

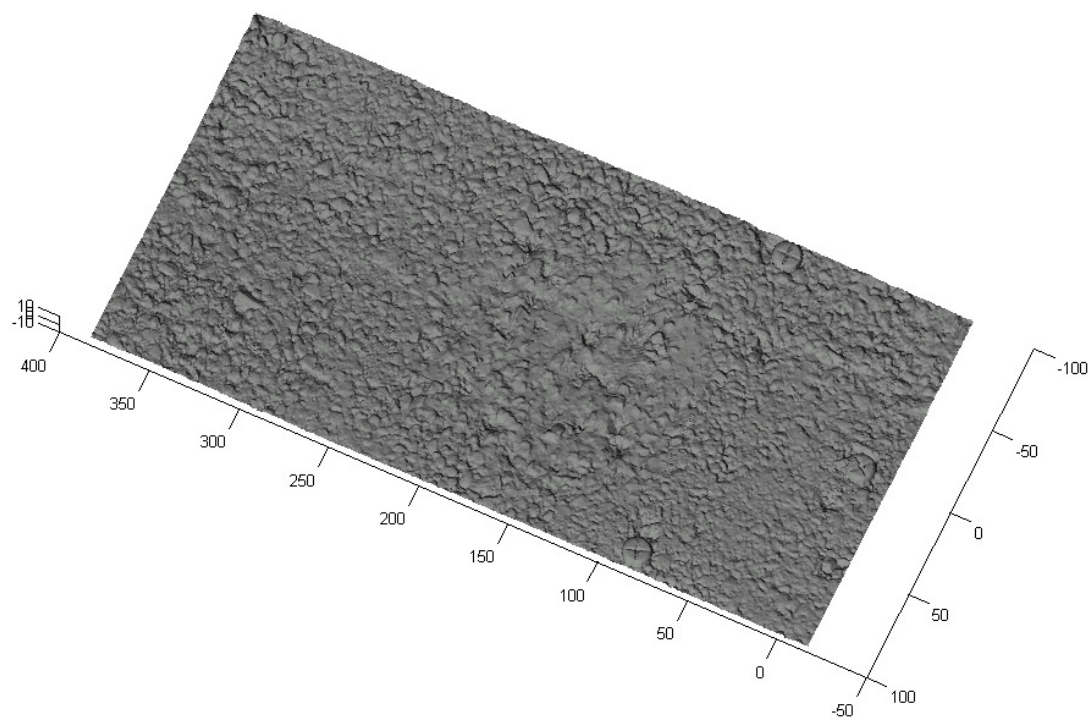


Figure 6 – Post-wear hot mix asphalt pavement surface

The wear analysis technique developed during the project involves comparing differences between the unworn and post-wear 3D surface coordinates of a test section. The scan horizontal coordinates are synchronised by rotating and translating the coordinates until the centres of each of the three survey spikes are aligned. The changes in surface characteristics are then determined by subtracting the post-wear scan vertical coordinates from the lightly-trafficked scan. Hence, if an aggregate particle is removed, it will appear in Figure 7 in its positive form in its original location, against a flat (unchanged) background.

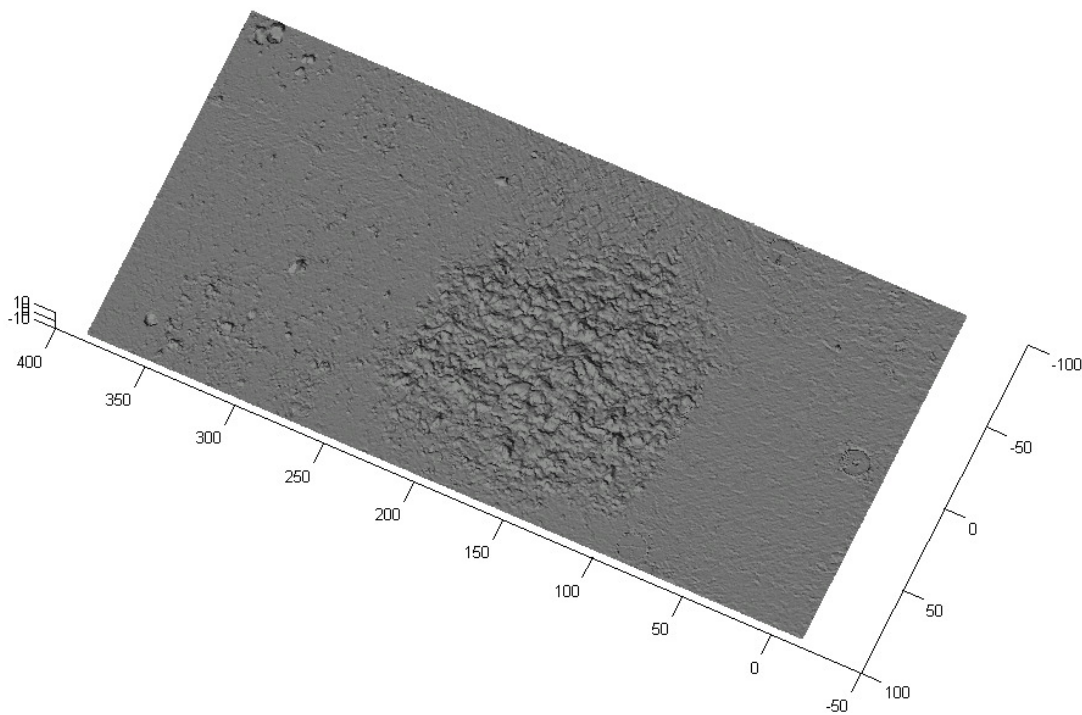


Figure 7 – Subtraction of lightly-trafficked scan from post-wear scan

By undertaking wear analysis in this manner, it was noted that several aggregate particles were removed from the top and left of the test section, possibly due to scrubbing forces when positioning the test tyre which took up to five attempts. This wear went unnoticed during visual and photographic analysis. Detailed analysis revealed 18 aggregate particles were plucked from the binder and a further 35 were sheared relative to their original position by the combination of horizontal and vertical stress applied to the pavement surface by the test tyre. Significant binder shearing over the top of remaining aggregate particles in the direction of gross contact patch horizontal force was observed in a section measuring 115 mm by 130 mm.

The 3D surface coordinates measured during each scan not only lend themselves to this detailed analysis of pavement surface wear but can also be manipulated to give results equivalent to traditional pavement surface texture methods. A 2D slice can be taken to give profile depth, mean profile depth and estimated texture depth (International Standards Organisation, 1997). A calculation can also be performed to calculate mean texture depth (International Standards Organisation, 1997) or sand patch texture depth (Austroads, 2008). A separate correlation study was performed with a range of surfaces from untrafficked to heavily-trafficked to compare measured sand patch texture depth and that calculated from the 3D surface coordinates with a specified grain size. Excellent correlation was achieved.

4. Conclusions

The equipment developed under the current research project was successfully deployed in the field yielding interesting results regarding the relationship between pavement surface wear and heavy vehicle tyre forces. An intentionally adverse, yet realistic, combination of vehicle configuration, loading and manoeuvre was simulated and it was found that due to gross slippage of the tyre contact patch, significant pavement surface wear was evident after only a single loading cycle.

The wear analysis technique developed allowed three failure modes particular to the pavement surfacing layer to be accurately identified. Some minor wear which was not identified using photographic analysis was also found. The ability to accurately locate the test wheel and to use a straight path with progressively steered test wheel instead of curved path with straight test wheel allows even small pavement surface test sites to be utilised. In the case of a B-double combination starting from rest on a steep grade, even the identification of a suitable test site is difficult and accurate vehicle positioning is often a very lengthy exercise with long turnaround times. The tyre test rig allows this manoeuvre to be simulated on a flat test site with a width of only 3 metres and 20 metre length.

It is hoped that the new techniques and equipment developed will eventually allow road owners to understand the tyre forces generated by new heavy vehicle combinations before they are assembled. This may allow appropriate pavement surface selection for specific sites where manoeuvres result in high shear stresses, such as rural T-junctions, climbing lanes, areas of traffic stopping, starting and channelisation. The improved identification and understanding of surfacing failure modes over their typical life cycles may also allow further progress in surfacing design. If these two aims can be realised, it will be possible to quantify the relationship between heavy vehicle tyre forces and pavement surface wear that currently does not exist in the literature.

5. References

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- International Standards Organisation (1997), ISO 1347-1 Characterization of pavement texture by use of surface profiles. Part 1: Determination of mean profile depth. Geneve, Switzerland, ISO.