The friction measuring tire / road surface space interface

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ABSTRACT

This paper considers how the tire of a friction measuring device interacts with the space between road surface aggregate particles. This space helps facilitate surface drainage and combines with a treaded tire in the bulk removal of water when trafficked in wet conditions. Unlike cars and trucks, the tires used on most friction measuring devices are typically smooth and without tread. It has been assumed for many years that use of this type of smooth tire represents a worst case scenario with respect to measuring a road surface. Aggregate particles will embed into the tire and the tire will deform around them and into the spaces between particles. Therefore, trying to better understand what might be happening and what is being measured becomes more difficult. This paper considers just the friction tire / space between aggregate particles interface. It summarises an investigation of different friction measuring tires using the Tire Embedment Apparatus (TEA) Mark I and II. These were developed to investigate the smaller and larger sizes of friction measuring tire respectively. This investigation removed many of the complicating factors to just those of the tire and the space. For the tire this considered tire wear, inflation pressure and applied vertical load under static laboratory conditions. For the space this considered distance between simulated particles and edge condition. It was found that the amount of tire displacement into the space increases with aggregate / groove wear, particle distance and applied vertical load. Displacement decreased as the tire becomes worn. For a given set of test conditions the amount of displacement into the space decreases until a critical value is reached at which there is no further reduction. Comparison of friction measuring tire data is made with those of treaded tires.

Key words: Tire embedment apparatus, tire / surface space.

Introduction

One of the conclusions of the European ROSANNE project was the principle of enveloping. This helps explain how aggregate particles embed into tire rubber and how the tire deforms into the space between particles. The principle of enveloping had been proposed by Hamet and Klein (2000) who were investigating the relationship between road texture spectra and calculated acoustic spectra. Although they were investigating noise, enveloping is fundamental to other road surface parameters such as rolling resistance and skid resistance.

Figure 1 shows an example of enveloping for an asphalt test specimen. This has been created by painting a 305 x 305 x 50 mm asphalt slab with blue paint and then subjecting it to simulated trafficking using the Road Test Machine located at Ulster University. The removal of paint shows the tire / asphalt envelope. It shows how the two full -size treaded test tires have interfaced with the surface texture of the asphalt test specimen. For this type of asphalt, the tire / asphalt interface essentially consists of isolated islands surrounded by blue paint denoting paths were water may either be trapped or dispersed.

Closer inspection shows areas where simulated trafficking has totally removed the bitumen to expose the tops of polished aggregate particles. At lower depth into the surface texture the bitumen coatings still remain until a critical depth is reached at which there is only blue paint. Similar patterns occur for most in-service asphalt mixes and change during the earlier stages of their life until equilibrium is reached.

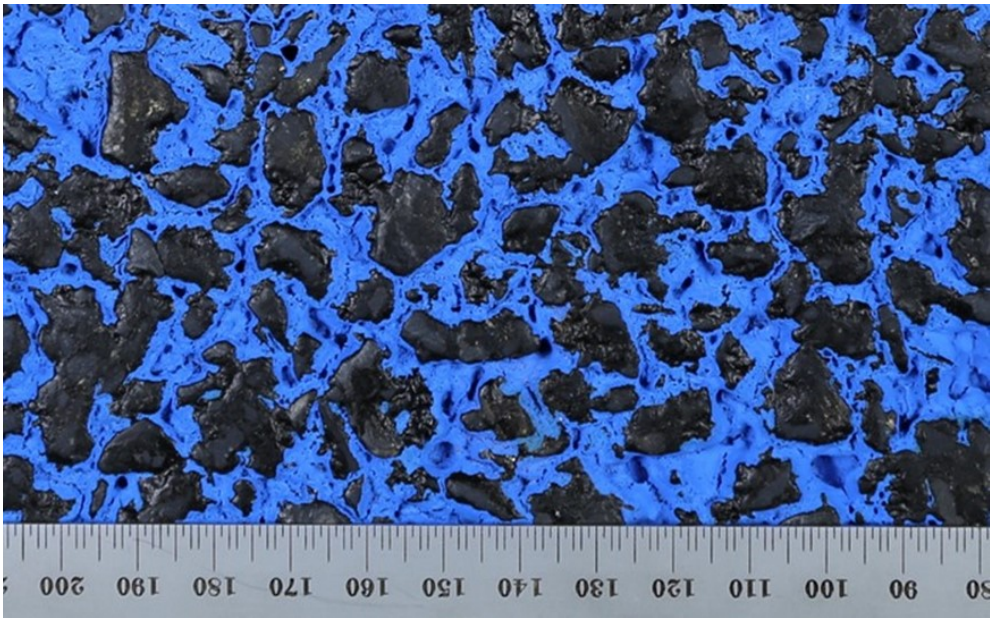

Figure 1. Enveloping of the tire / asphalt interface shown by paint removal.

Enveloping also occurs for the standard test methods of polished stone value (PSV) and Friction after Polishing (FAP). Dunford (2013) painted FAP test specimens to show how the rubber polishing rollers made contact with the aggregates being assessed for skid resistance. Woodward et al (2016) repeated this work using painted PSV test specimens. 3d modelling determined that enveloping due to the solid rubber tire used in the PSV occurred to a depth of approximately 0.4 mm into the test specimen.

Both the FAP and PSV studies found parts of individual aggregate particles not being assessed during these laboratory tests. In comparison, the full-size tire is making contact with all of the upper texture of the blue painted asphalt shown in Figure 1. There would appear to be a difference in what standard test methods such as PSV and FAP are doing in comparison to how real pneumatic tires interface with both the aggregate particle surface and that of the road surface texture.

So what is happening at the interface? For simplicity consider a free rolling tire. For example, it takes any part of its contact patch approximately 0.0003 seconds to traverse a 10 mm aggregate particle at a driving speed of 120 kmh. This could also represent the distance between 2 adjacent aggregate particles. Both distances apply to the principle of enveloping. In comparison, a human blink lasts between 200 and 400 milliseconds. During this very short time period the tire envelopes the road texture. If its raining water needs to be displaced. For a given vehicle / tire / road / manoeuvre combination there will be a critical speed / water thickness at which the enveloping interface is detrimentally compromised.

Being able to understand the enveloping principle within the context of the dynamic contact patch is therefore fundamental to either laboratory testing, field measurement or providing a road surface for the driving public. This requires better understanding of how ordinary tires interact with the road. It also requires better understanding of how standard tires used in the measurement of friction, noise and rolling resistance interact with the road surface. It needs better understanding of the interface conditions of laboratory methods such as PSV and FAP. It may be argued that there is limited value in measuring something that is different to what happens on a road and then using these measurements as the basis of material selection and specification of road surfacings.

As concluded by both Dunford and ROSANNE, the road / tire interface is complex. Much of the research currently being reported is difficult for most to apply to the real world. This has prompted what may be considered as the somewhat simplest investigations summarised in this paper i.e. development of a simple test method to investigate interaction between a tire and a road surface. There are no new complex or theoretical models. Rather, this paper reports basic data that may help to better understand the enveloping principle.

Test equipment to investigate the tire / road envelope space

Two test apparatus were developed to investigate the space between aggregate particles into which a tire may embedment or deform into. The Tire Embedment Apparatus Mark 1 (TEA MK1) was designed to investigate the small diameter ASTM friction tire fitted to a GripTester. The TEA MK2 was designed to investigate the larger diameter tires such as those fitted to a sideways force friction device. The TEA MK2 can also be used to investigate tires fitted to cars and vans.

To simplify matters, enveloping was considered to be the amount of tire embedment or deformation that may occur into the space between coarse aggregate particles as a result of surface macrotexture or the grooves associated with runways. An idealised macrotexture was simulated using two steel plates which could be moved apart to create a gap of known width. This ranged from approximately 6 mm to a maximum of 150 mm. The influence of aggregate particles embedding into the rubber was not considered.

During a test the test tire is lowered unto a gap or space between two plates and the amount of tire embedment or deformation into the gap spacing is measured giving a simple measure of enveloping. This simple setup allowed the inter-relationship between factors such as tire inflation pressure, tire wear, applied vertical load, steel plate edge profile and gap spacing width to be explored.

The TEA MK1 apparatus is based on a Wessex wheel tracker typically used for permanent deformation testing of asphalt mixes. Figure 2 shows a loaded ASTM friction measuring tire sitting across a gap spacing with the depth of embedment / deformation into the space being measured. Five sets of edge profile were assessed using the TEA MK 1. These were : straight (90^0 angle), stepped, fillet, 45^0 angle and chamfered. A digital tire thread depth gauge was fitted to a stand and used to record the depth of tire embedment or deformation between a set of plates with similar edge profile.

Two ASTM friction test tires were evaluated. One was nearly new, the other was worn beyond the stage when it should have been replaced. Vertical load was varied by adding weights to the end of the arm fitted to the modified wheel tracking device. The vertical loads used were 9.1, 11.3, 17.0, 23.8, 27.2 and 29.4 kg.

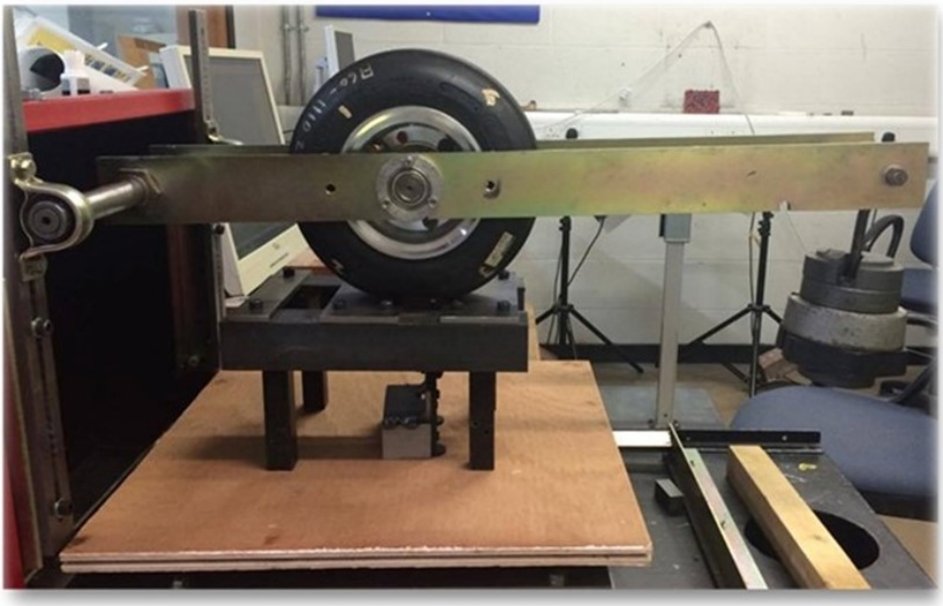

Figure 2. The TEA MK1 apparatus.

Approximately 700 tests were carried out during the TEA MK1 investigation. Many of the findings were predictable. For example, the depth of embedment was found to increase with gap space. For a given gap space the amount of embedment increased as applied vertical load increased. A minimum gap space was found below which there is almost no change in the amount of tire embedment. This is illustrated in Figure 3 which plots data relating to a 233.4 N vertical load and inglation pressure of 20 psi. The minimum gap space for this test condition is approximately 15 mm at which there is approximately 0.5 mm of friction tire embedment. This gap space of approximately 15 mm was the same for all the vertical loads assessed. With respect to tire wear there was slightly more embedment for the nearly new tire.

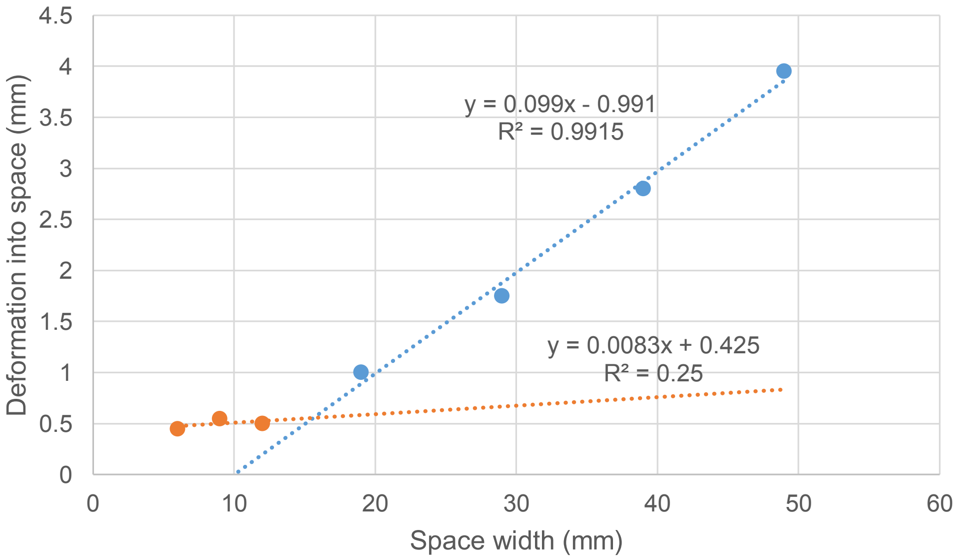

Figure 3. Nearly new tire, 20 psi, 233.4 N load, measured in central position, straight edge profile.

The TEA MK 2 is shown in Figure 4. It is similar to the TEA MK1 but with larger dimensions and constructed with stronger materials to withstand greater loads. Different treaded and smooth friction measuring tires have been assessed. For example, a trailer tire with a maximum allowable inflation pressure of 95 psi allowed investigation of heavier loadings. The standard inflation pressure for a sideways force tire is 350 kPa or approximately 50 PSI. Testing was carried out at 15, 30 and 50 psi for the sideways force tire and 20, 50, 60 and 95 psi for the trailer tire.

Figure 4. The TEA MK2 apparatus.

The simulated gap spacing was created using two plates cut from high tensile steel to withstand the greater applied loadings on the apparatus. The edge of each plate had two shapes i.e. straight and rounded. Reversing the ends allowed either a vertical straight edged gap or a rounded gap to be available for testing. Figure 5 shows a sideways force tire deforming into the space between two straight end plates.

Figure 5. Sideways force tire deforming into the space between plates.

The variables investigated include tire type, gap spacing, edge detail, vertical load, amount of deformation during loading and unloading. The amount of tire deformation for each gap spacing / tire type / inflation pressure was recorded as each weight was added and as the weights were removed. Again, many of the findings were similar to those of the TEA MK1 investigation. At the 9.8 mm gap spacing, increasing the applied load did not cause any significant increase in the amount of deformation into the gap space. The amount of embedment into the space during loading and unloading was the same. At the 150 mm gap spacing, increasing the load caused a significant increase in the amount of deformation. Linear relationships were found between gap spacing and deformation into the gap spacing. There was little difference between the two loading conditions especially at the smaller gap spacings for the nearly new and worn sideways force tires.

The amount of deformation for the trailer tire was found to be less than for the sideways force tire. The amount of deformation was less influenced as load was increased. Figure 6 compares the new and worn sideways force tires with the treaded trailer tire at the same inflation pressure of 345 kPa and load of 2.16 kN. This shows the two sideways force tires to embedment more into the space compared to the trailer tire. At the smallest gap spacings the two types of tire are similar. However, as gap spacing increases the sideways force tire deforms to a greater amount into the gap space.

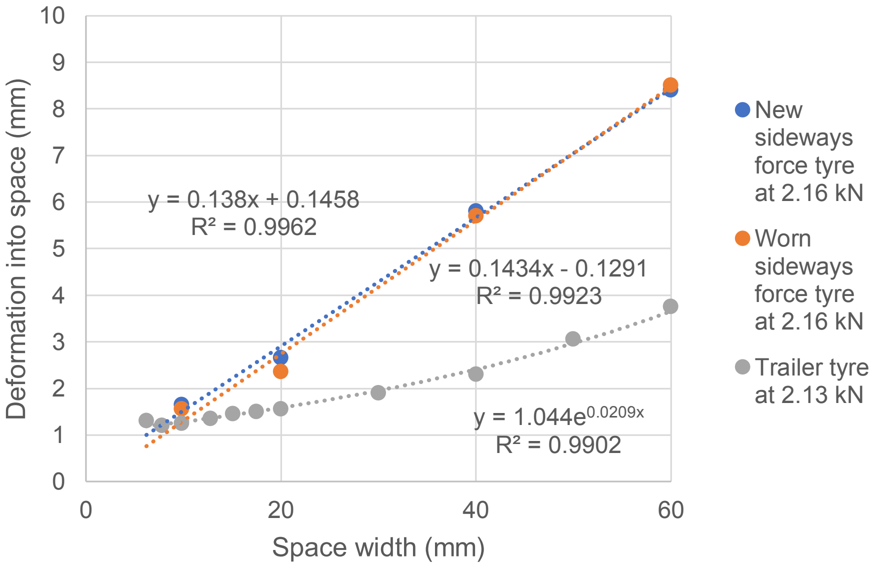

Figure 6. Comparison of tires for gap spacings up to 60 mm at similar vertical load of 2.16 kN.

Conclusions

This paper has considered the principle of enveloping, specifically the measurement of tire embedment into the space between idealised aggregate particles created by road surface texture. The TEA MK1 and MK2 test apparatus have tried to simplify a complicated 3d interface.

They have removed the influence of speed by testing in a dry static test condition. Indeed, many friction models are based on laboratory experiments at relatively slow speeds or static conditions. Within the context of enveloping and noise, Hamet and Klein (2000) reported that interaction is almost independent of speed. Given the actual contact times involved i.e. in the order of a few milliseconds, it may be assumed that the amount of found embedment could be less with increasing speed.

The influence of aggregate particle size, shape and microtexture has been removed and replaced by a smooth steel surface. The 3d asphalt macrotexture has been replaced by a space of known distance between two steel edges with a known profile. Enveloping is a three dimensional interface based on x , y and z spatial data. Tire embedment into the space between two parallel plates considers just the y and z directional co-ordinates.

The laboratory investigations considered factors that can be controlled and thought to influence the envelope space. Under static conditions and for all of the test conditions investigated, the main factor relating to tire embedment is gap width. With respect to the TEA MK1 and MK2 apparatus this is the space into which a tire deforms occupying part or all of the available void.

For each tire evaluated there are distinct trends in the data. The amount of tire embedment decreases in a predictable manner until a critical gap space is reached. The amount of embedment then remains fairly constant as gap space is further decreased.

At the smaller gap spaces it would appear that the larger diameter sideways force tire behaves in a similar manner to a treaded tire. However, with increasing gap space there is more embedment (enveloping) for the sideways force tire compared to the treaded tire reported in this paper.

Tire wear did not significantly affect the amount of deformation into the gap space for the two friction measuring tires. This is interesting considering the significant difference in vertical pressure distribution within the contact patch shown by pressure mapping new and worn tires.

In conclusion, the TEA MK1 and MK2 test apparatus offer a simple means of investigating the principle of enveloping. The investigations summarised in paper have found relationships relating to skid resistance and other surface texture related properties such as noise and rolling resistance.

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