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Development of a reference surface for the assessment of pavement skid resistance measurement devices

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Executive Summary

Providing adequate levels of skid resistance is an important task for road owners, as a key component for road safety. Highways England's skid resistance policy requires direct annual measurement of low speed skid resistance across the whole strategic road network. Sideway-force Coefficient Route Investigation Machines (SCRIMs) are used for the routine monitoring of the skid resistance condition of the English Strategic Road Network.

Currently there are approximately 18 machines in the UK fleet of SCRIMs. To ensure consistency of measurement across the fleet, the performance of machines is currently managed through an accreditation process carried out annually. The accreditation process can be summarised as; comparing measurements made by individual machines, with the average of those made by the fleet as a whole.

This method of accreditation is capable of identifying machines which have a performance that differs from the fleet as a whole on the day of testing. However a limitation of this technique is that changes in the performance of the fleet, year on year, cannot be identified. This is because the skid resistance of typical pavement surfacings (including those used as part of the annual accreditation) changes with weathering and trafficking. Therefore, should the average performance of the fleet change from year to year this could either be as a result of actual changes in the performance of the fleet, or as a result of natural changes in the skid resistance of the surfaces tested.

Accrediting machines by making measurements on a surface with a known and unchanging skid resistance, would ensure the stability of the fleet performance and improve the accuracy and confidence of measurements made on the road network.

It is the aim of this work to identify materials that could be used as a reference surface for all skid resistance testing machines, but in particular, materials that could be used as reference surfaces for accrediting SCRIMs. It should be noted that it is not the aim of this work to determine the absolute skid resistance performance of these surfaces, but to assess the overall performance of the materials.

The properties of a reference surface for this application are defined as either:

- a surface that is used over a long period of time and retains its skid resistance properties through use, weathering and storage, or,
- a surface that is used as a disposable system and has the same initial skid resistance properties but does not retain these characteristics through use, weathering or storage.

The work was undertaken in 6 stages:

1. Desk study of previous works and potentially suitable materials,
2. Laboratory testing of materials identified from the desk study,
3. Development of a system for full scale testing,
4. Full scale testing,
5. Results analysis,
6. Assessment of materials.

Potentially suitable materials were identified through a desk study. Initial laboratory testing of a selection of candidate materials was carried out to assess the change in skid

resistance performance under SCRIM-like testing conditions. The results from the laboratory testing highlighted three materials that warranted further investigation:

- Mini-mesh – A glass reinforced plastic material with a porous grid texture.
- Anthracite tile – A smooth porcelain floor tile
- LEGO® - A moulded plastic comprised of tessellated cylindrical plastic nodes.

These materials were then tested under full scale conditions at Membury airfield and consisted of trafficking each candidate material in turn using a subset of the SCRIM fleet. Skid resistance measurements were then made at several points during the trafficking using SCRIM, and two other skid resistance testing devices. The results gathered provided a set of results for each surface that was used to characterise the change in skid resistance for each surface as a result of trafficking with SCRIM.

The results from the full scale testing were used to identify the amount of initial polishing required until after which no substantial change in skid resistance value was identified. The analysis showed that the Mini-mesh and LEGO® required an amount of initial polishing, well within what is practically achievable, the Anthracite tile required no initial polishing.

The results of this work can be concluded as follows:

- The materials tested in the full scale trial; LEGO®, Mini-mesh and Anthracite floor tile, can all be used as reference surfaces for SCRIM devices, subject to the appropriate wear in periods being adhered to.
- The combination of all three materials would provide a robust means of accrediting SCRIMs across their working range.
- The performance of the materials may differ depending on the device used to measure skid resistance.
- To fully implement the materials as references for SCRIM the absolute performance, and the long term performance of the materials must first be ascertained.
- In order to use these materials as references for other devices, more detailed measurements with those devices will be required.

1 Introduction

The aim of this work is to identify material options for use as a reference surface for skid resistance testing devices, and to explore how these may be used in practice.

1.1 Background

Sideway-force Coefficient Route Investigation Machines (SCRIMs) are specified for the routine monitoring of the skid resistance condition of the UK strategic road network (Department for Transport, 2015). Figure 1-1 shows the Highways England Skid Resistance Development Platform (SkReDeP); a research tool for the development of skid resistance standards and equipment which is based on a SCRIM.



Figure 1-1 SkReDeP

Currently, the performance of individual SCRIMs is maintained via calibration of the measurement load cells, and regular consistency checks on selected road surfaces (British Standards Institution, 2006). The performance of the UK SCRIM fleet is managed through an Annual Accreditation Trial (AAT), (Pavement Condition Information Systems, 2013). The AAT can be summarised as, comparing measurements made by individual machines, with those made by the average of the fleet.

The AAT is capable of identifying machines whose performance differs from the fleet on the day of testing. A limitation of this technique is that changes in the overall performance of the fleet, year on year, cannot be identified. This is due to the variability in the skid resistance of typical pavement surfacings (including those used as part of the AAT) with weathering and trafficking. Changes in the average performance of the fleet could either reflect actual changes in the fleet performance, or result from normal surface variability.

Accrediting machines by making measurements on a surface with a known and unchanging skid resistance would:

- Ensure the stability of the performance of the fleet.
- Improve the accuracy and confidence of measurements made on the road network.
- Allow the performance of individual machines to be assessed without the need for the rest of the fleet.

1.2 Report outline

The following flow chart shows the structure of the report and how the outcomes of each task were used throughout the work.

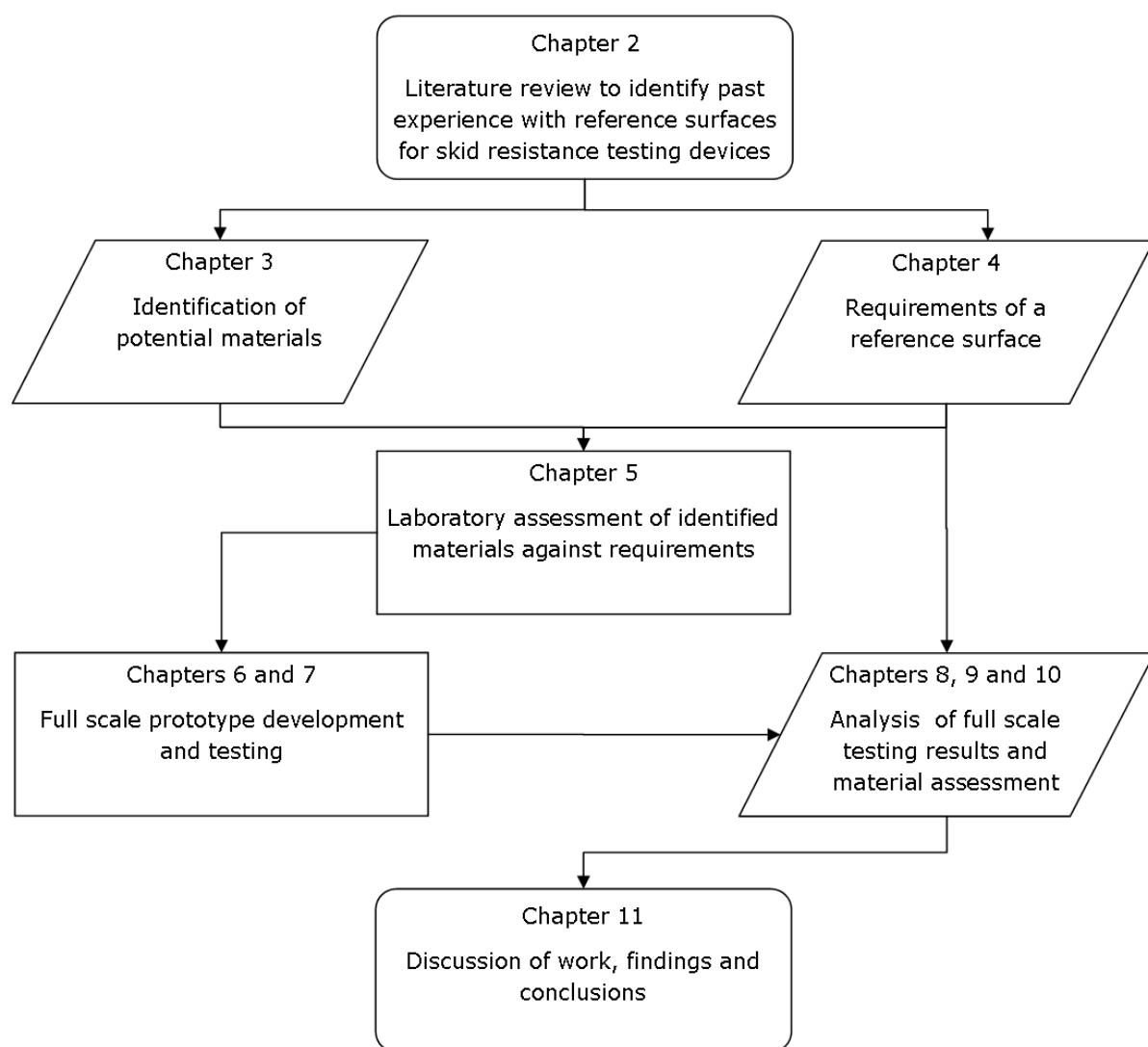


Figure 1-2 Report outline flow chart

2 Previous experience with reference surfaces

The development of a skid resistance reference surface has been studied comprehensively in 2 recent European Commission (EC) funded projects. These were carried out by members of the Forum of European national Highway Research Laboratories (FEHRL), as summarised in the following sections. These were the only works that were identified on the subject of skid resistance reference surfaces.

2.1 The tyre and road surface optimization for skid resistance and further effects (TYROSAFE)

The tyre and road surface optimization for skid resistance and further effects (TYROSAFE) project is a European collaborative project which makes up part of the FEHRL strategic research programme. Work package 2 of this project is focussed on the harmonisation of skid resistance devices and the deliverable from task 2.2 of this work package reported the state of the art of test surfaces for skid resistance (Forum of European National Highway Research Laboratories, 2009).

This work concluded that many different test-surfaces are used across Europe for the verification of skid resistance measurement devices. Ideally test track surfaces not subject to the same trafficking levels as public roads would be used for the verification for skid resistance measurement equipment. However, because there are relatively few test tracks in Europe, many operators use public roads which have unstable skid resistance characteristics. Moreover the use of in service carriageways limits operators to the types of materials that can be tested and excludes very low friction surfaces. No information was provided in this document regarding the skid resistance performance of the verification surfaces.

2.2 Harmonisation of European Routine and research Measuring Equipment for Skid resistance (HERMES)

Harmonisation of European Routine and research Measuring Equipment for Skid resistance (HERMES) project is also an European collaborative project contributing to the FEHRL strategic research programme. The project was completed in 2006 and the findings of the work are reported in FEHRL report 2006/01 (Forum of European National Highway Research Laboratories, 2006).

2.2.1 Literature review

A task of the HERMES project was to evaluate the feasibility of designing a reference surface for calibrating friction testing devices. Section 5.3.3 of the HERMES report (Forum of European National Highway Research Laboratories, 2006) provides a review of literature into previous attempts to develop a reference surface as summarised in the following paragraphs.

During the 1970s five Primary Reference Surfaces (PRS) were installed at three test centres in the USA with the backing of the Federal Highways Administration (FHWA). The PRS were constructed from naturally occurring surfaces such as silica-sand and river gravel, bound with an epoxy seal coat. It was found that although the PRS were located at test centres and only trafficked during testing, the seasonal variation in the surface was substantial and, for example, the skid resistance of one surface at one site reduced by 27% over a 9 year period (Huckins, 1977).

In 1983, Dunlop Limited investigated the creation of reference surfaces and proposed a standard reference surface to the International Organisation for Standardisation (ISO). The aim of the surface construction was to use quartz sand to replicate microtexture of traditional surfacings. It was found that the microtexture of the reference surfaces closely replicated that of traditional surfacings but that the microtexture was rapidly removed through the polishing action of tyres (Eldridge, et al., 1986).

The Dunlop proposal could therefore not be considered as a standard reference surface but it was taken into account by ISO. In 1986 ISO published a technical report (ISO/TC22/SC 9, 1986) detailing the procedure for manufacturing a high friction reference surface using silica sand. Silica sand was selected as it was the most wear-resistant material available at the time.

In 2002 a report published by the American National Aeronautics and Space Administration (Wambold & Henry, 2002) detailed work into the assessment of the skid resistance properties of a number of surfaces on an airfield site at Wallops Island. Measurements were made over a 9 year period on eight different surfaces:

- Concrete surface
- Concrete surface with 1x1/4x1/4 inch grooves and canvas belt finishing
- Concrete surface with 1x1/4x1/4 inch grooves and burlap drag finishing
- Aggregate asphalt
- Aggregate asphalt with 2x1/4x1/4 inch grooves
- Aggregate asphalt with 1x1/4x1/4 inch grooves
- Aluminium plate
- Driveway sealed coated asphalt

Measurements of skid resistance were made using a number of devices at numerous test speeds, the results showed an inherent instability in skid resistance value measured on all of the surfaces and so was considered that none of the surfaces tested had the potential to become a long term solution.

2.2.2 Requirements for a reference surface

The HERMES project identified a matrix of properties that a reference surface should possess to be considered suitable for the calibration and verification of skid resistance devices. This matrix is provided in Table 2-1, it assumes that the surface shall be of modular construction.

Table 2-1 Outline requirements for calibration reference surfaces (Forum of European National Highway Research Laboratories, 2006)

General Property	General Requirements	Other Comments
Alignment	Straight and level, no cross-fall	These requirements would apply to the track on which vehicles run as well as the test surface. With no crossfall, suitable drainage or other mechanisms will be needed to rapidly clear excess water from the test surfaces.
Length	100 meters minimum	This is the minimum test length. A longer length (up to 300 m) may be required to accommodate some devices that use a fixed slip ratio controlled by a servo system that responds to changing surface friction.
Width	1 meter wide test surface	There will also be a need for space either side of the test surface when installed to allow for the passage of the test vehicle, depending upon the relative alignment of the test wheel and the main vehicle's tyres.
Construction	Similar interlocking modules, size to be chosen to suit ease of construction and handling.	The load bearing capacity for the installed module and associated roadway will need to be able to support normal lorry axle weights in order to accommodate the larger test vehicles.
General	Texture (micro and macro) of the surfacing should be homogeneous along its length and across its width. The texture should not be so aggressive that it causes excessive test tyre wear.	Each module should be similar, with no significant boundary edges in the surface where the modules join. Joints will need to be secure and not collect dirt or allow passage of water (unless suitable subsurface drainage provided).
Surface characteristics	Surface HH BFC ₂₀ ¹ = 0.75-0.85 MPD ² = 1.5-2.0 mm Surface HL BFC ₂₀ = 0.75-0.85 MPD = 0.2-0.4 mm Surface LH BFC ₂₀ = 0.25-0.35 MPD = 1.5-2.0 mm Surface LL BFC ₂₀ = 0.25-0.35 MPD = 0.2-0.4 mm	These are tentative suggestions of target ranges for the key texture parameters. Eventually, a more precise specification will be needed. BFC (locked-wheel) values at 20 km/h have been used here as a suggested indicator of the micro texture level needed: in practice, other low slip speed measurements could be used.
Surfacing materials	To be determined.	Should not be bitumen based or use untreated crushed rock aggregate.
Stability	Should maintain defined skid resistance and texture depth over a practical temperature range for at least 3 years. Friction should not change over a short period of repeated testing.	To assist this, it may be necessary to keep and use the surfaces in a controlled environment.
Durability	Should maintain defined skid resistance and texture depth for up to 1000 repeated test passes with up to 500 kg test wheel load.	The suggested number of passes is sufficient to check up to 5 devices (making 5 test passes at 3 speeds plus some additional passes) 3 times a year for 3 years.

¹ Braking Force Coefficient measured at 20 km/h; The ratio between the longitudinal and vertical force acting on a test tyre when the tyre contact patch is moving at the same speed as the test vehicle.

² Mean Profile Depth; the average value of the profile depth measured over a certain distance.

3 Identification of possible surface materials

To gather information about possible materials that could be used in the development of a reference surface, a desk study was carried out into the properties of a number of material types.

Initially, materials used in the calibration, or verification, of laboratory skid resistance measurement equipment were assessed. Materials used in the construction of alternative trafficked surfaces, such as temporary car parks or high friction surfacings, were also assessed as-well-as any other materials that were identified as being potentially suitable.

3.1 Reference surfaces used by laboratory skid resistance testers

3.1.1 The portable skid resistance tester

The Portable Skid Resistance Tester (PSRT, aka pendulum tester) is a skid resistance testing device that uses a rubber slider to measure skid resistance. British standard BS EN 13036-4:2011 (British Standards Institution, 2011) defines the use of the PSRT and requires that before a new slider is used, or if a slider is excessively worn it should undergo a conditioning and verification process. The verification of PSRT sliders requires measurements to be made on three reference surfaces, shown in the following images.

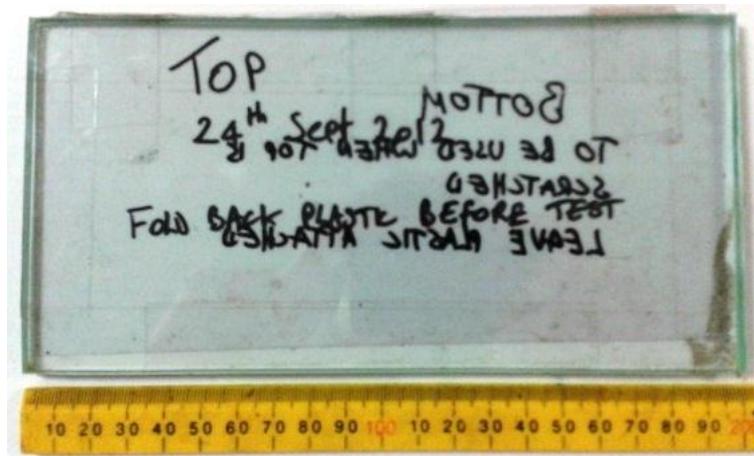


Figure 3-1 Float glass – A smooth piece of glass



Figure 3-2 Reference tile – A pavigrés ceramic tile



Figure 3-3 Verification film – fine grade pink lapping paper

The float glass and verification film are readily available from a number of suppliers, these are manufactured consistently and so may be used from any batch produced from any supplier. The ceramic tile can also be purchased from a number of suppliers, but, must be supplied from a single batch of tiles produced by pavigrés some years ago. This is evidence that suggests variability of the tiles between manufacturing batches.

3.1.2 The Wehner-Schulze machine

The Wehner-Schulze machine (W-S) is an accelerated polishing and friction testing machine. The friction test is carried out by three rubber feet attached to a spinning test head. Before a friction test is carried out a verification test is carried out on a textured glass plate (Figure 3-4) to ensure that the rubber feet are performing correctly.



Figure 3-4 The Wehner-Schulze machine verification plate

The plate is supplied by the equipment manufacturer on the purchase of a W-S. The plate is replaced when measurements consistently outside of the accepted range are measured by the W-S friction testing station.

3.2 Alternative surfacing materials

3.2.1 High friction surfacings

TRRL report LR 466 (Hosking & Tubey, 1972) describes work carried out to identify materials suitable for use as high friction surfacings. The report details road trials and laboratory measurements carried out to assess the skid resistance and wear resistance of a number of synthetic and natural aggregate types. The work concluded that Refractory Aggregate Super Calcined (RASC) grade calcined bauxite gave the best performance in terms of skid resistance and wear resistance. None of the other aggregate types tested provided a suitable performance to be used in high friction surfacings. In particular, crushed glass was found to have poor resistance to polishing and poor adhesion to the binder material.

3.2.2 Steel coated road blockers

Previous works into the polishing resistance of coatings applied to steel road blockers was conducted by TRL. This work was conducted under a confidentiality agreement with the client and so the results of this testing cannot be published. The general outcomes of the work can however be summarised.

Friction values obtained before and after polishing in the W-S machine showed that; sand, granite, calcined bauxite or carborundum particles encapsulated in resin were able to provide a relatively small change in friction with polishing.

The results of testing also showed that surfaces constructed from natural stone aggregates or metal do not retain their skid resistance properties as well as the encapsulated systems.

3.2.3 Portable roadways

Portable roadways are modular systems, usually constructed from plastic or composite materials, that can be used to quickly build temporary roadways or parking areas. Below is a list of some available products that may be of interest to this work:

- Autotрак medium duty roadway – 3 m x 1.2 m panels made from recycled polypropylene.
- Autotрак rhino mats - 1.1 m x 1.1 m panels made from recycled polyethylene.
- Rola-trac iTrac - Snap-together systems for pedestrians and heavy vehicles.
1.2 m x 0.92 m panels made from polypropylene co-polymer
- TuffTrak - 3 m x 2.5 m panels made from high density polyethylene.

The friction performance of these materials is not provided by the manufacturers.

3.3 Other materials

3.3.1 Elastomeric materials

Previous work carried out by TRL in 2009, subject to a confidentiality agreement, looked into the skid resistance and polishing resistance of two rubber compound products.

The two products were put through a programme of polishing and friction testing in the W-S, PSRT measurements were also made. The PSRT results show that there is a small change in value as a result of polishing. It is suspected that the W-S measurements, that are made at 60 km/h were affected by the friction feet aquaplaning on the low texture surface. W-S measurements made below 10 km/h were more consistent with PSRT measurements. Given that measurements are made with SCRIM at 50 km/h the potential for aquaplaning on surfaces of this type should be considered.

3.3.2 Other plastic materials

Other plastic materials warranting consideration, may be similar to those used in temporary road surfacings, but utilising different surface textures or plastics.

One example is the moulded plastic systems used in children's construction toys such as LEGO® or Duplo®. These systems use Acrylonitrile Butadiene Styrene (ABS) plastics whereas portable roadway systems tend to use Polyethylene based (PE) plastics. Table 3-1 is an excerpt from a larger table of typical mechanical properties of plastic materials (Professional Plastics, 2015). The coefficient of friction should be regarded as indicative (no detail is given about how it was measured), and it is clear the hardness of ABS and PE plastics differs substantially so the ability of these materials to maintain their skid resistance properties may also be different.

Table 3-1 Mechanical properties of plastic materials (excerpt from (Professional Plastics, 2015))

Material	Coefficient of friction	Hardness (Rockwell)
Polyacrylonitrile butadiene styrene (ABS)	0.5	100 - 110
Polyethylene – High density	0.29	60 - 73
Polyethylene – Low density	N/A	41 - 46

3.3.3 Composites

Composite materials can be defined as:

"a combination of a matrix and a reinforcement, which when combined gives properties superior to the properties of the individual components" (Composites UK, 2015)

By this definition a traditional asphalt material can be defined as a composite³. However a more useful class of materials is fibre reinforced materials, such as Glass fibre Reinforced Plastic (GRP).

In a traditional engineering context composite materials are primarily used as structural elements due to their benefits in weight and strength over other materials. Composite materials are used in a few applications as surfacing materials, these are primarily pedestrian walkways. No information could be identified as to the use of composite materials as a surfacing material for vehicular traffic and so the performance of these materials with trafficking is not well understood.

³ The matrix being the bitumen binder and the reinforcement being the aggregate particles.

3.4 Selection of materials for laboratory testing

Based on the review of literature available and the knowledge of surface properties gained the following surface types were assessed in the laboratory testing stage:

1. Ceramics
2. Abrasive sheets
3. Metals
4. Plastic
5. Composites
6. Calcined bauxite materials

Further details of the materials selected for laboratory testing can be found in Chapter 5. These surfacings have been selected as they have been considered to provide the most promising solutions, or where little is known about the material. The review suggested that traditional pavement surfacing materials are not suitable as reference surfaces, but these have been included to act as a control.

4 Surface requirements

The objective of this chapter is to develop a framework that can be used to assess the applicability of candidate materials for use as skid resistance reference surfaces. The requirements of a reference surface can either be met by a long term or short term system. For instance a material may be able to keep its skid resistance properties over a long period of time when exposed to weathering and polishing, but that material may be costly or have inconsistencies in production.

Equally, a material may be able to be produced to provide a repeatable skid resistance, at a low cost but its properties may change when exposed to trafficking. Both systems could be used as a reference surface, the first as a permanent system and the second as a disposable system

There may be cases where a surface can be used as a combination of the scenarios above. A surface of this type would possess ideal attributes, Table 4-1 shows required surface characteristics in more detail.

Table 4-1 Ideal performance characteristics

Parameter	Long term system	Disposable system
Polishing resistance & wear from usage	One hundred, or greater, sets of measurements can be made before the surface requires replacing.	A single set of measurements (enough to assess one device) can be made before the surface requires replacing.
Consistency of production	Performance of surface is consistent throughout the length of a single surface, but multiple items may not be completely consistent.	Performance of surface is consistent throughout the length of a single surface, plus items can be made by multiple manufacturers.
Aprox. SC(50)	0.1 – 1.0	0.1 – 1.0
Recyclability & disposal	All components of system require disposal in landfill.	All components of system can be re-cycled after use.
Robustness, including water resistance	One hundred, or greater, sets of measurements can be made before the surface requires replacing.	A single set of measurements (enough to assess one device) can be made before the surface requires replacing.
Weathering resistance	Under normal usage and storage conditions the surface can be kept in a usable condition for one year.	N/A
Shelf life & storage		
Cost of production	High	Low
Cost of supporting engineering		
Portability & installation	More than two people are required to install surface in one day using multiple HGVs.	One person can install surface in less than one hour using manual handling and one van.

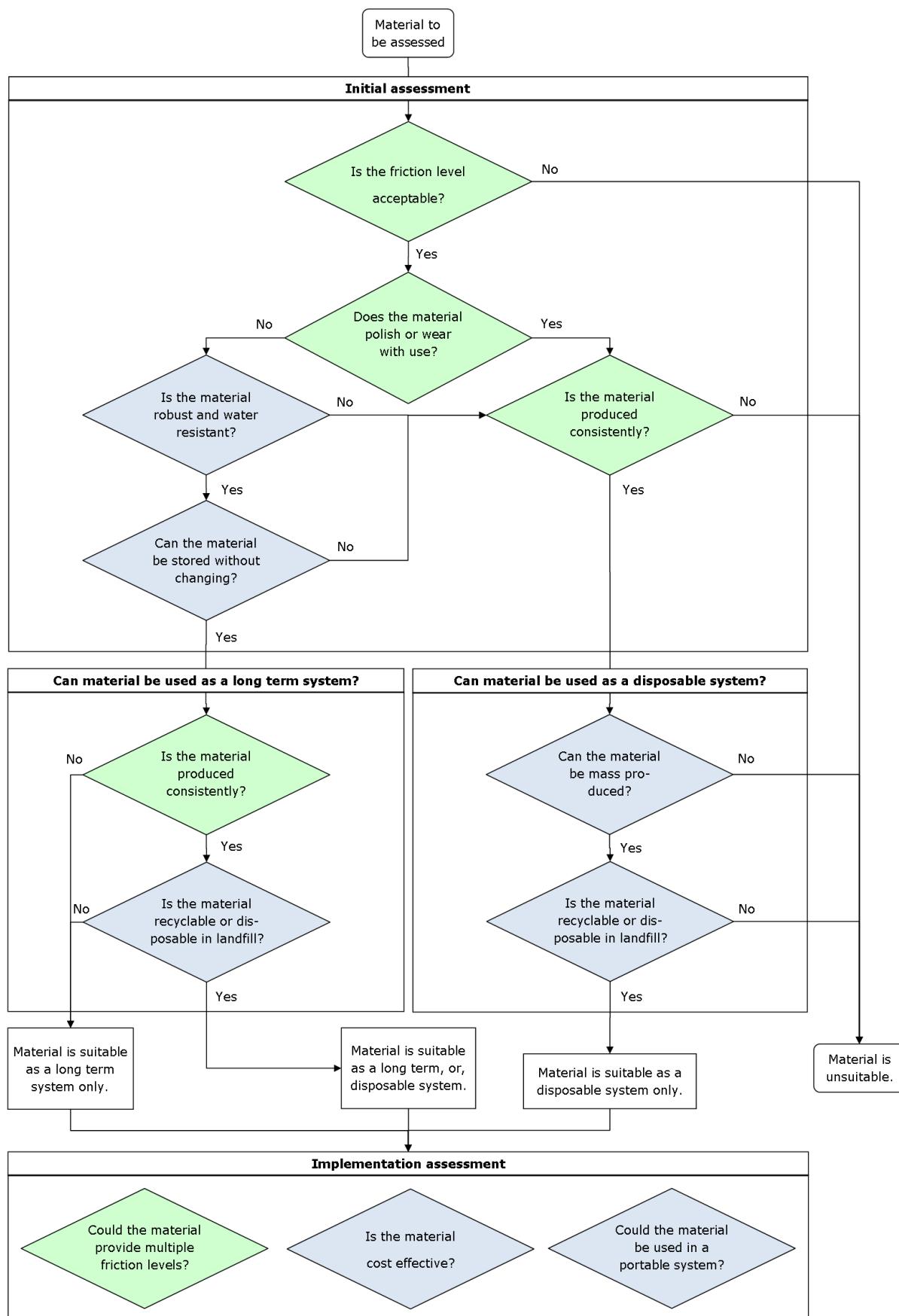
The flow chart in Figure 4-1 consists of a number of questions that have been designed to identify materials that are suitable as a reference surfaces. The questions highlighted

in green indicate those that can be answered through testing. The questions highlighted in blue can, initially, be answered using available literature or through supplier liaison, although any claims will have to be eventually tested in practice.

The flow chart has been separated into four sections. The first section, Initial assessment, is designed to identify materials that have the potential to be used as reference surfaces based on skid resistance performance only.

The next two stages take a closer look at the materials and identify materials that can be used as a long term system, disposable system, or both. At this stage a "first pass" sanity check is also carried out to dismiss materials that it would not be possible to use as disposable system due to their ability to be mass produced or recycled.

The final stage of assessment looks in more detail at the applicability of the material for implementation. This stage takes into consideration, cost, portability and the ability of the material to provide multiple friction levels.

**Figure 4-1 Flow chart of material assessment**

5 Laboratory assessments

The laboratory testing carried out was designed to answer the “green” questions in Figure 4-1. The testing was carried out to identify promising candidate materials that could be further assessed in full scale trials.

5.1 Laboratory procedure

The laboratory testing was carried out using a Wheel Tracking Machine (WTM), with skid resistance testing using the PSRT. When set up in its scuffing configuration, with an angled pneumatic wheel, it was considered that the WTM would provide a similar polishing action to a SCRIM test tyre.

The WTM (Figure 5-1) is designed to test the resistance of road surfaces to rutting and abrasion. The procedure for assessing the abrasion of road surfaces is provided in Appendix G of TRL Report TRL176 (Nicholls, 1997), this methodology was used as guidance for the laboratory assessments.

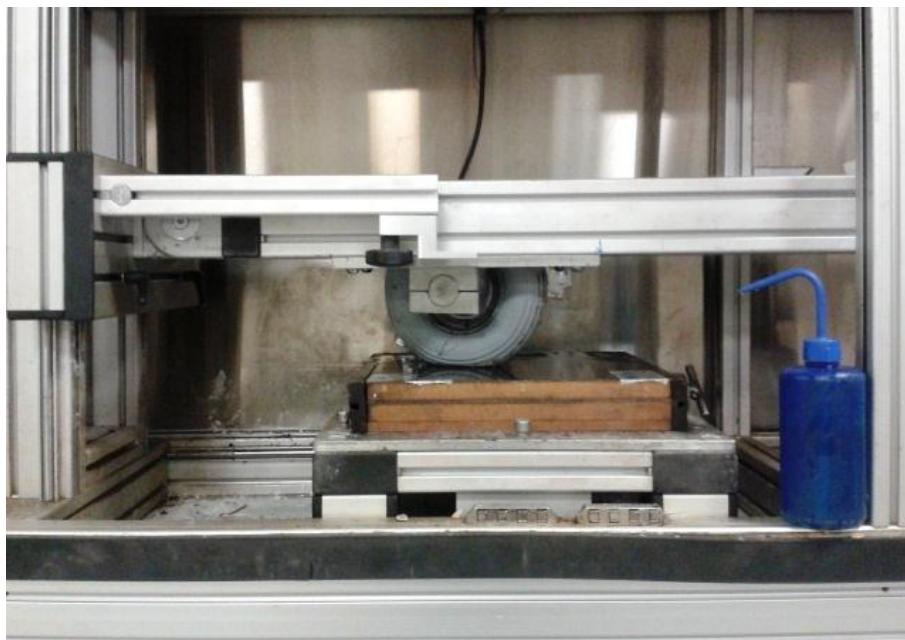


Figure 5-1 A silicon carbide abrasive specimen mounted in the WTM

The machine is operated by mounting a test specimen onto an oscillating base that moves underneath a static, freely rotating tyre loaded to 520 N. The tyre used for the abrasion testing was a pneumatic ribbed tyre, mounted at 20° to the direction of oscillation. The procedure used in this work differed from that reported in TRL176 in that the abrasion of the test samples was carried out under wet conditions by periodically manually wetting the surfaces.

The polishing action provided by the WTM compares to that of a SCRIM test wheel in the following ways:

- The angle of the test wheel of both machines is the same.

- The average speed achieved by the WTM throughout its oscillation cycle is 0.13 m/sec (0.47 km/h), approximately 1/10th of the standard test speed of SCRIM, 14 m/sec (50 km/h). However, as friction decreases with speed (Sanders, et al., 2015), the friction, and therefore the wear between the wheel tracking tyre and surface specimen is likely to be greater than would be experienced with a SCRIM tyre at this lower speed.
- The tyre / contact pressure estimated (Appendix A.1) for the scuffing tyre used in the WTM (320 kPa) is approximately 100 KPa greater than that generated using a SCRIM tyre (425 kPa).
- The application of water in the WTM was designed to avoid dry contact.

This analysis suggests the WTM may produce a more aggressive action on the surface specimens than the SCRIM test wheel. For SCRIM, there will be an additional action as a result of the vehicle wheels; it has been assumed that this will be a lower order effect than the angled test wheel which is skidding across the surface. The laboratory testing was therefore considered a good test of the surfaces ability to retain their skid resistance properties as a result of SCRIM testing.

The PSRT is comprised of a rubber, spring loaded slider, attached to a weighted swing arm and a mechanical readout scale. As the rubber slider makes contact with the surface the force between the surface and the slider slows the swing arm. The distance travelled by the swing arm after the slider has contacted the surface is registered on the scale by a needle and manually read, and recorded as a pendulum test value (PTV).



Figure 5-2 The portable skid resistance tester

The PSRT was used as is defined in British standard BS EN 13036-4:2011 (British Standards Institution, 2011).

The following sections explain how the WTM and PSRT were used together to answer the questions in Figure 4-1.

5.1.1 *Is the friction level acceptable?*

It is not the aim of this work to characterise the absolute performance of the candidate materials. However a knowledge of the indicative friction performance of the surfaces is necessary in order to assess their applicability for use as reference surfaces.

Initial testing (before abrading in the WTM) with the PSRT characterised the nominal friction level of the surface. The acceptable range of 0.1 – 1.0 SC(50) stated in Table 4-1 effectively represents the typical working range of a SCRIM; based on experience this has been interpreted as a range of PTV of 10 to 110, a "Yes" answer was therefore given if a PTV value was measured in this PTV range.

5.1.2 *Does the material polish or wear with use?*

Each surface received a total of 500 abrasion passes in the WTM. PSRT testing was carried out at; 0, 10, 25, 50, 100, 250 and 500 passes to characterise the performance of the surfaces as they were abraded.

BS EN 13036-4:2011 (British Standards Institution, 2011) states that the reproducibility of the pendulum test when using a slider with a Shore A hardness of 96 (as used in this study), ranges from a standard deviation of 1.5 to 4.5. The PSRT measurements were assessed against the upper limit of this range, 4.5. This identified if changes in the skid resistance performance of the surfacings exceeded the possible variation in the measurement technique. The following tests were used for the assessment of the change in friction with polishing:

- If the range of all measurements was less than the upper limit of the PSRT reproducibility, 4.5, then the question was answered "No".
- If the range of all measurements was greater than 4.5, but the 90th percentile range of values lower, then the question was answered "yes", but, with the caveat that further investigation could be useful.
- If the 90th percentile range of all measurements was greater than 4.5 then the question was answered "yes" with no caveat.

5.1.3 *Is the material consistently produced?*

A number of specimens of the same material were gathered from different suppliers, or different manufacturing batches from the same supplier. If the range of initial PTVs was less than 4.5 the question was answered "yes".

5.1.4 *Could material produce multiple friction levels?*

Different constructions or grades of material were sourced and tested with the PSRT. If a range of PTV values greater than 30 was obtained from different variants of the same material the question was answered "Yes".

5.2 Materials selected for laboratory testing

5.2.1 Ceramics

There is a precedent for using ceramic tile as a reference surface, as a particular batch of ceramic tiles selected by the UK Slip Resistance Group is listed as one of the reference surfaces for the verification of Pendulum Tester sliders in BS EN 13036-4 (BSI, 2011).

Three specimens of each of the following tiles were obtained, each specimen was gathered from different manufacturing batches to assess the between batch variability:

- Black anti-slip tile "Santarem" from Pavigrés (Figure 5-3) with an "R13⁴ finish".



Figure 5-3 Anti -slip tile

⁴ "R" Numbers are indicative of the skid resistance performance of ceramic tiles. The procedure for determining the R numbers is given in DIN 51130 (DIN, 2014).

- Porcelain Graphite Structured tiles from "Core Effect" (Figure 5-4). This is described as a dark grey full bodied porcelain floor tile with a textured surface to create an anti-slip effect. Its slip resistance properties are graded as R11.

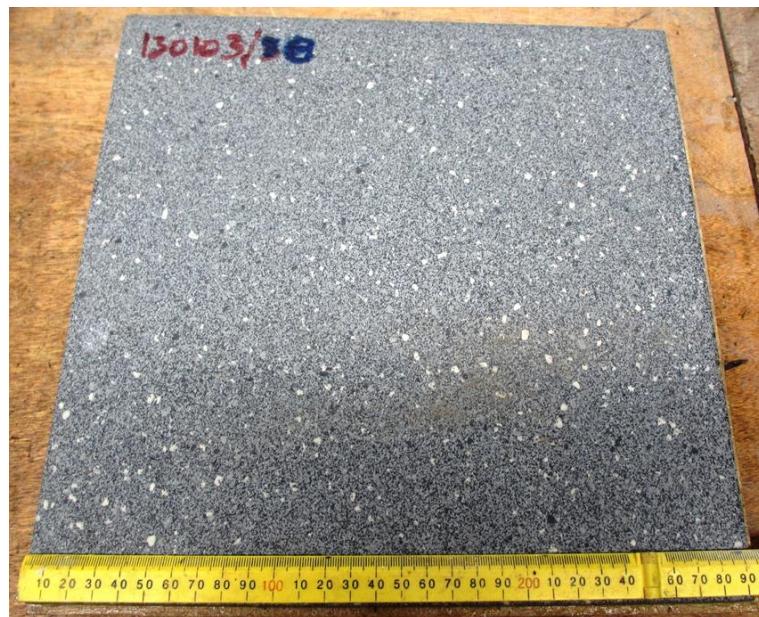


Figure 5-4 Graphite structured tile

- Ceramic Anthracite tile from the Grey range by Envy (Figure 5-5) having a "subtle textured surface" giving an R10 grading.

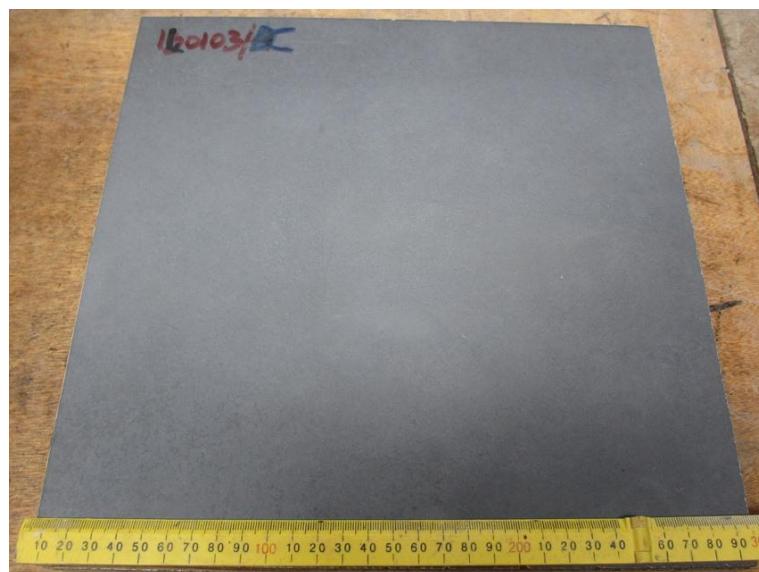


Figure 5-5 Anthracite tile

5.2.2 Abrasives sheets

An abrasive sheet (P400 grade silicon carbide (SiC) paper (British Standards Institution, 2011)) is used in the preparation and verification of PSRT sliders. To assess its longer term abrasive properties a sample of waterproof heavy-duty cloth backed P400 SiC abrasive was obtained.



Figure 5-6 SiC Abrasive paper

In addition to the P400 grade SiC abrasive paper, other specimens were obtained of different grades to assess the potential for SiC abrasive to provide multiple friction levels. In addition, abrasive paper using Aluminium Oxide (AlO) abrasive particles were obtained to assess the effect of using this different abrasive material.

5.2.3 Metal

Samples of 3 mm thick steel tread-plate with a raised diamond pattern (50mm x 20mm grid) were acquired from three different suppliers. Materials were obtained from different suppliers to assess the variation in manufacturing.

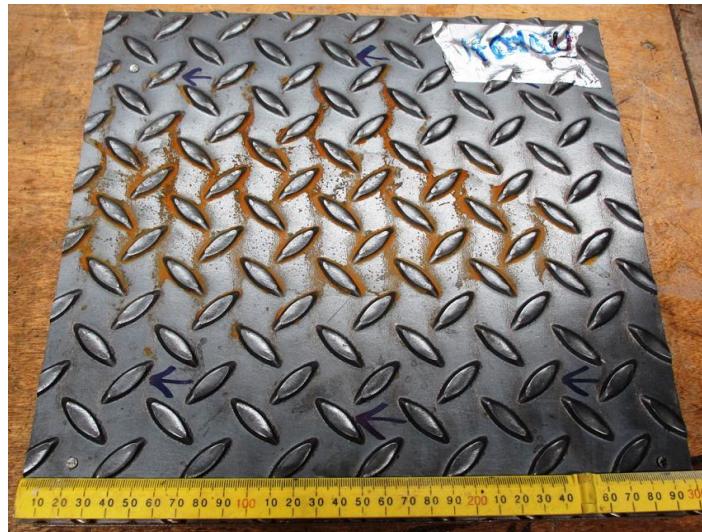


Figure 5-7 Steel plate specimen

5.2.4 Plastics

A number of temporary plastic modular roadway systems were identified through a small desk study. The majority of the systems possessed a very coarse texture. This posed an issue for testing with the PSRT as the length of the PSRT contact patch could not fully characterise the surface friction. One system (Rolla Track plastic temporary flooring (Figure 5-8)) was identified with a surface comprised of parallel ribs and grooves 10 mm wide. This panel was marked with the recycling symbol for Polypropylene.

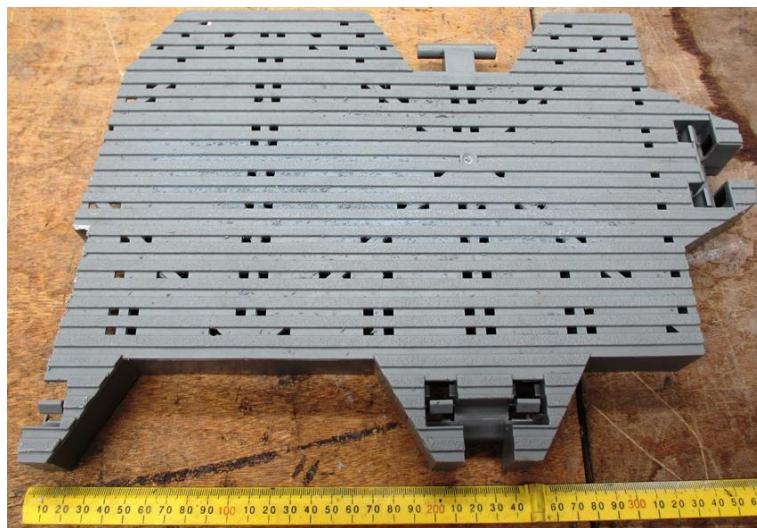


Figure 5-8 Rolla Track plastic temporary flooring

In addition to the commercially available systems designed to carry vehicular traffic, the properties of moulded plastic systems not currently, but which could potentially, be used as surfacing materials were also assessed. LEGO®, referred to in this document as Lego, (Figure 5-9) is a moulded plastic material comprised of tessellated cylindrical plastic nodes. It is readily available and was considered to offer a potential alternative to traditional plastic surfacings.



Figure 5-9 Lego specimen

5.2.5 Composites

DeckSafe solid panel top (Figure 5-10), comprised of an internal glass reinforced plastic (GRP) grid structure covered with a solid top. The top is constructed from a GRP sheet covered in a non-slip aggregate encapsulated with resin.

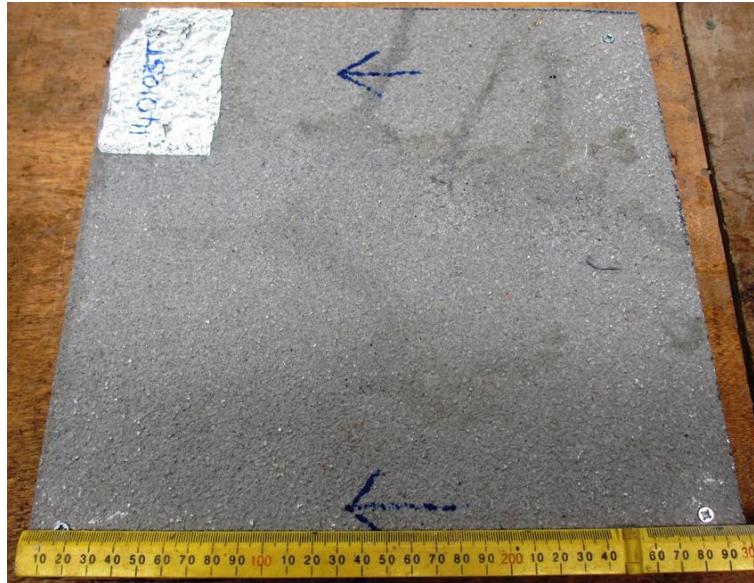


Figure 5-10 DeckSafe solid panel top

DeckSafe Mini-mesh (Figure 5-11) is a similar construction to the solid panel top but with an exposed grid structure. The mesh surface is made up of 12 mm x 12 mm holes and 6 mm wide grid surface. The grid surface is coated with the same non-slip coating as the solid panel top.

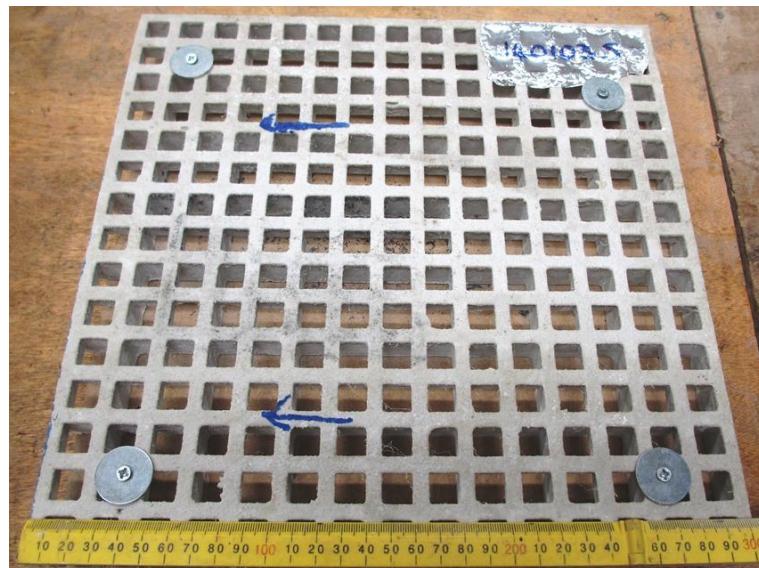


Figure 5-11 DeckSafe Mini-mesh

5.2.6 *Calcined bauxite materials*

Calcined bauxite materials are specified for use in road construction as high friction surfacings (Department for Transport, 2006). The calcined bauxite aggregate is extremely resistant to polishing, and is bonded to the surface by a methyl methacrylate resin. Stirling Lloyd provided the following materials for laboratory assessment:

- Chinese calcined bauxite with a coarse aggregate between 0.9 and 1.4 mm
- Chinese calcined bauxite with a coarse aggregate between 1.0 and 3.0 mm



Figure 5-12 Chinese bauxite 0.9-1.4 mm (left) and 1-3 mm (right)

- Guyanan calcined bauxite with a coarse aggregate between 0.9 and 1.4 mm
- Guyanan calcined bauxite with a coarse aggregate between 1.0 and 3.0 mm



Figure 5-13 Guyanan bauxite 0.9-1.4 mm (left) and 1-3 mm (right)

In addition, to create a similar surface with different skid resistance properties. A material using pea gravel with a coarse aggregate between 1.0 and 3.0 mm was also developed by Stirling Lloyd and included in the laboratory testing.



Figure 5-14 Pea gravel 1-3 mm

5.2.7 *Traditional thin surface course systems*

To act as a control surface, a thin surface course system TSCS typical of those used for in-service road construction was added to the set of specimens used in the laboratory testing. The specimen (Figure 5-15) was manufactured in TRL's asphalt mixing laboratory and was comprised of a 10 mm, 55 PSV⁵ aggregate using a 50 pen⁶ bitumen binder and constructed to Table D.1 of PD 6691:2015 (British Standards Institution, 2015).



Figure 5-15 10 mm TSCS

⁵ PSV = Polished stone value

⁶ Pen = penetration, this refers to the test used to ascertain the hardness of the binder (British Standards Institution, 2015)

5.3 Laboratory testing results

An account of the laboratory measurements and how they were used to answer the questions in Figure 4-1 is given in Appendix A and Appendix B. Table 5-1 presents the conclusions of the assessment of each of the materials.

Table 5-1 Summary of results from laboratory testing

Material	Is the friction level acceptable?	Does the material polish or wear with use?	Is the material produced consistently?	Conclusion
Anti slip tile	Yes	Yes	Yes	Material may be suitable as a disposable system only.
Graphite structured tile	Yes	Yes	No	Material is unsuitable.
Anthracite ceramic tile	Yes	No	Yes	Material may be suitable as a long term or disposable system.
SiC abrasive paper	Yes	Yes	Yes	Material may be suitable as a disposable system only.
AIO abrasive paper	Yes	Yes	No	Material is unsuitable.
Diamond steel plate	Yes	Yes	No	Material is unsuitable.
Rolla-Trac plastic temporary flooring	Yes	Yes	N/A	Material is unsuitable.
Lego	Yes	No	Yes	Material may be suitable as a long term or disposable system.
Deck Safe solid panel top	Yes	Yes	No	Material is unsuitable.
Deck Safe Mini-mesh	Yes	Yes, but further investigation could be useful	Yes	Material may be suitable as a long term or disposable system.
Chinese bauxite	Yes	Yes	No	Material is unsuitable.
Guyanan bauxite	Yes	Yes	No	Material is unsuitable.
Pea Gravel	Yes	Yes	No	Material is unsuitable.
10 mm TSOS	Yes	Yes	No	Material is unsuitable.

The results from the laboratory testing have shown that the following surfaces may be suitable as a reference surface:

Material	Mean PTV	Long term	Disposable
Anthracite tile	22.0	Yes	Yes
Deck Safe Mini-mesh	83.3	Yes	Yes
Lego	35.1	Yes	Yes
Non slip tile	30.9	No	Yes
SiC abrasive paper	87.5	No	Yes

Since the mean PTV provided by the non-slip tile was similar to that of the Lego surface and the mean PTV of the SiC paper was similar to that of the Mini-mesh. It was decided to use the; Anthracite tile, Mini-mesh and Lego during the full scale testing as these systems benefit from being suitable as a long term and disposable system. Descriptions of these materials may be found in Appendix E.

6 Full scale prototype development

The full scale testing of materials presents a number of challenges not present in the laboratory, including:

1. Supporting the load applied to the surfaces by the test vehicles,
2. Providing an area for the test vehicles to achieve the required test speed and to manoeuvre,
3. Providing an area where the test surfaces could be installed,
4. Achieving the required amount of trafficking in an efficient manner,

This chapter discusses how these challenges were met in the full scale testing.

6.1 Required properties of prototype system

In order to assess the properties of the candidate materials at full scale, it was necessary to develop a system that would allow the installation and trafficking of the surfaces. In order to properly assess the surfaces, the system must have the following properties:

- Provide a flat and level surface for the candidate materials to be installed on,
- Allow the candidate materials to be affixed securely so that they remain stable during testing,
- Allow skid resistance testing vehicles to make repeated measurements,
- Allow testing to be conducted in a controlled and safe environment.

This requires an area that is free of other traffic such as a closed, in-service road, or private area, such as a test track or airfield. An ideal solution for a permanent installation would be to recess and bond the surfaces to an existing road / test track surface. However project constraints meant that this was not possible as road and test track surfaces have to be restored to their original condition after testing. To this end the following further properties must also be met by the system:

- Allow installation of the candidate materials without bonding or fixing to the underlying surfaces,
- Allow the test area to be restored to its original condition after testing.

6.2 Development of surface prototype

The first development of the surface prototype was a proof of concept to ascertain the best methods for supporting the candidate materials. The basic concept of the surface prototype was a free standing modular unit 3.6 m wide and 9.6 m long that would allow each of the candidate materials to be secured for testing (Figure 6-1). In order to gain the standoff required to support the thickest surface, the Mini-mesh, the surface of the prototype had a required standoff of 70 mm.

Initial testing of the prototype was carried out to assess the applicability of the engineering for a full scale trial. In particular the; surface rigidity, ease of installation, surface stability, repeatability of testing, and impact on the underlying surface, were assessed.

To gain the required standoff a solution was developed based on a temporary roadway base and plywood sheets. Figure 6-1 shows the basic design of the prototype construction.

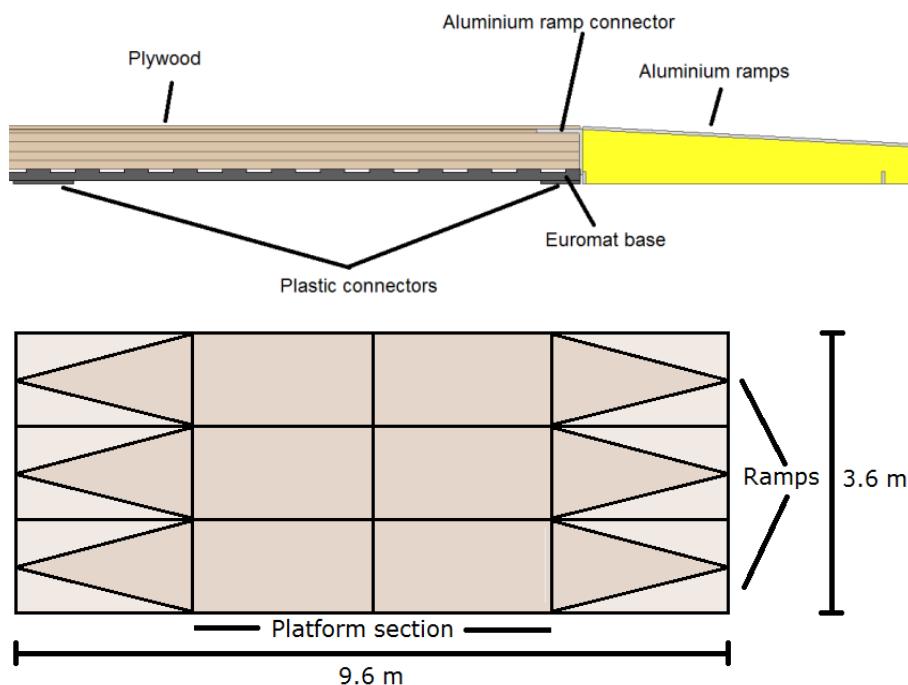


Figure 6-1 Basic design of the prototype surface construction

The prototype was a 3×2 panel modular system based on the dimensions of the roadway base (1.2×2.4 m), plastic screw connectors support the base and allow for the plywood panels to be secured in position using recessed bolts. Aluminium ramps were manufactured and connected to the platform via an aluminium angle plate which would secure the trailing edges of the ramp to the top of the platform.

6.3 Installation and testing

For initial tests, a short length, 4.8 m, of the surface was built on a section of the small roads system of the TRL test track. The surface was then trafficked using SkReDeP. Visual observations of the surface rigidity were made, supplemented by video recordings. The stability of the surface was assessed by measuring the movement in the surface after each trafficking pass.

The surface was installed on as flat and level an area as was available, but, a slight downward slope was present in the direction of travel. Figure 6-2 shows the finished prototype surface.



Figure 6-2 The finished prototype surface

The surface was trafficked using SkReDeP (Figure 6-3 shows stills taken from videos) at speeds from 10 km/h to 40 km/h in 5 km/h increments. It had been intended to carry out testing at a speed of 50 km/h, as this is the standard test speed for SCRIM devices, but this was not possible given the site geometry. Passes were made primarily with the skid resistance testing wheel up but two measurement runs were made with the wheel down at 25 km/h and 40 km/h.



Figure 6-3 Video stills of trafficking

6.3.1 *Observations for further development*

On the whole, the prototype surface offered a promising solution for full scale testing. However a number of observations were made (Table 6-1) which prompted several considerations for design alterations for the surface to be used as part of a full scale trial.

Table 6-1 Observations from prototype testing

Observations		Considerations for further development
1	Surface rigidity	<p>As the wheel travels along the ramp the leading edge lifts as the wheel moves to the trailing edge. (Figure 6-4).</p>  <p>Figure 6-4 Example of ramp leading edge lifting</p> <p>No structural changes in the ramps were observed during the tests.</p> <p>The base mats and plywood assembly showed flex under load.</p>
2	Ease of installation	<p>The surface was installed using 4 members of staff, a medium wheelbase van and battery operated power tools. Installation time was one day (8 hours) and dismantling time was half a day (4 hours).</p>
3	Surface stability	<p>No discernable transverse movement. 2 mm movement after each run in the direction of travel.</p>
4	Repeatability of testing	<p>No substantial changes in load measurement were observed. Although some pitching of the vehicle was observed in the direction of travel.</p>
5	Impact on the underlying surface	<p>No discernable effect was observed on the underlying surface.</p>
6	Cost	<p>The cost of materials for the manufacture of the prototype was £6451.57</p>

6.4 Further development of surface prototype

6.4.1 Rectification of issues identified from initial testing

In response to the observations made as part of the initial prototype assessments, the following amendments to the surface design were made.

To address observation 1:

- The ramp material was changed to solid plywood from welded aluminium – this increased stability, and allowed the ramps to sit evenly on the road surface, reducing movement when trafficked.
- The ramp angle was reduced from 3° to 1° – this reduced the forces applied to the platform when trafficked, reducing the risk of ramp lift. This also addresses observation 4.
- A flat section was added to the trailing edge of the ramps to remove the pivot point for ramp lift.
- The aluminium connection at the ramp trailing edge was replaced with plastic connectors mounted underneath the platform.
- The plastic roadway base was removed and the plastic connectors recessed into the plywood base.

To address observation 2:

- The additional flat section added to the ramps removed the need for an extra panel to allow SCRIM to sit level before the start of the testing section – this reduces overall length of the testing surface and installation time.
- The platform height was reduced from 70 mm to 36 mm - this reduced the total weight, production time and installation time required⁷.

To address observation 3:

- The trial site used was as flat as possible to reduce the risk of surface movement.

To address observation 6:

- For practical implementation, the length of reference surface needed to achieve a good repeatability of measurement is 100 m, as recommended in Table 2-1. This was however not feasible within the constraints of the project. For the full scale trial it was decided to construct the surfaces with the minimum possible length to obtain robust data. This was judged to be 10 m.
- Birch plywood was used for full scale construction instead of the more expensive marine plywood. However, birch ply is not treated for use in wet conditions and so an aluminium primer was used to seal the wood from water ingress.

⁷ Thinner Mini-mesh was found to be available from the manufacturer.

6.4.2 Adherence of reference surface candidate materials

A trial of three adhesives was carried out to ascertain the most suitable adhesive to secure the candidate materials to the plywood base. A desk study identified three suitable adhesives based on the claimed properties of water resistance, bonding capabilities for different materials, working time, spread rate and cost. The three adhesives selected were; Wakol MS 260 Wood floor adhesive, Evo-Stik Tile Adhesive and Evo-Stik Contact Adhesive.

The adhesives were tested by bonding a sample of the Lego and ceramic tile⁸ to an untreated plywood surface, and a plywood treated with aluminium primer. The application of the adhesive was carried out as per the manufacturer's instructions.

The positions of the bonded materials were marked and then trafficked using SkReDeP. Any movement in the materials was then assessed against the marked positions, signs of de-bonding were also visually identified. Table 6-2 summarises the observations made as part of this testing.

Table 6-2 Observations from adhesive testing

Observations			Considerations for further development
1	Application of adhesive	<p>The WAKOL MS 260 was applied easily and could be applied to a larger area with relative ease.</p> <p>The Evo-Stik Tile Adhesive was comprised of a two part system which required mixing.</p> <p>The Evo-Stik contact adhesive was applied easily, but had a short working time of ten minutes.</p>	<p>A mechanical mixer may be appropriate to mix large quantities.</p> <p>Applying adhesive to a larger area would be challenging in a ten minute window.</p>
2	Ability to achieve a level surface	<p>The WAKOL MS 260 could pose some issues with the Lego as it has a dense consistency and so is applied in a fairly thick layer.</p> <p>The Evo-Stik Tile Adhesive was able to achieve a level surface.</p> <p>The contact adhesive showed the most promise. For achieving a level surface.</p>	<p>It should be endeavoured to apply this adhesive in a thin layer if adhering the Lego.</p>
3	Bonding properties	<p>The WAKOL MS 260 bonded both Lego and tile well to the primed and untreated plywood. No signs of cracking or movement were observed.</p> <p>The Evo-Stik Tile Adhesive bonded all of the materials well to the untreated plywood. However the bond with the primed surface proved to be insufficient.</p> <p>The Evo-Stik contact adhesive reacted poorly with the Lego surface causing the plastic to become malleable and to lose its shape when trafficked.</p>	<p>The Evo-Stik Tile Adhesive should not be used on the primed plywood.</p> <p>The Evo-Stik Contact Adhesive should not be used for bonding the Lego.</p>

⁸ The Mini-mesh was excluded from this assessment, during the laboratory testing phase, mechanical fixings were used, and this was deemed to be appropriate for full scale testing. Although adhesive was also used to add redundancy.

In summary the WAKOL MS 260 was found to be the most appropriate solution, but care should be taken when adhering the lego surface to ensure a level finish.

6.5 Final design of the surface prototype

The final design of the surface prototype was developed in order to address the observations made as part of the preliminary testing. Figure 6-5 shows the basic final design of the prototype system.

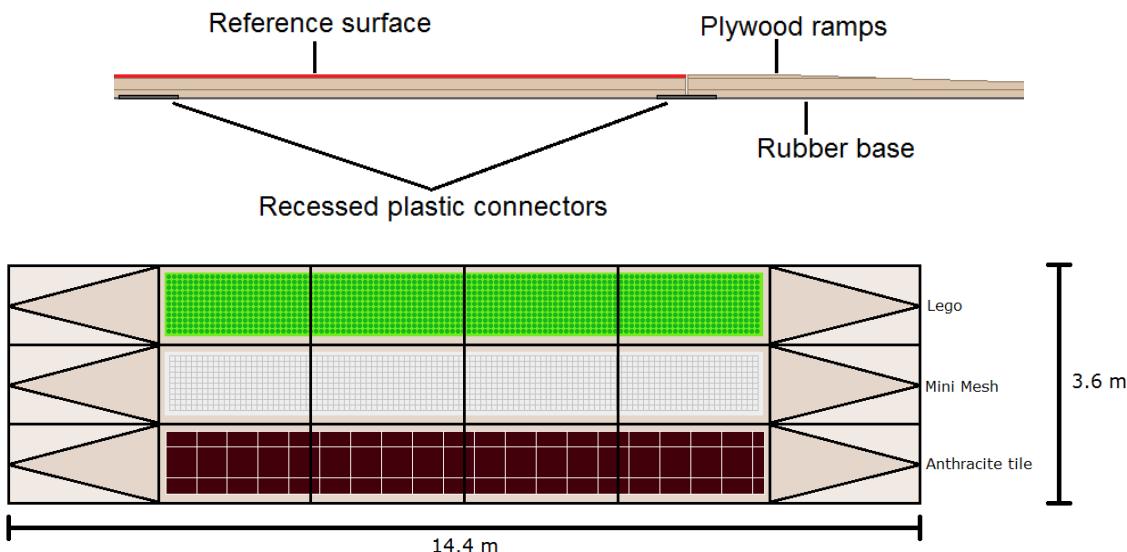


Figure 6-5 Basic final design of the prototype surface construction

The final prototype design is a 3×4 panel modular system based on the dimensions of the roadway base (1.2×2.4 m). The recessed plastic screw connectors support the base and allow for the panels to be secured in position using mechanical fixings. Plywood ramps were manufactured to a height of 36 mm at an angle of 1 degree. The panels supporting the reference surface were manufactured to various heights so that when the surfaces were applied the 36 mm height was maintained. The technical drawings of the plywood bases are given in Appendix C.

7 Full scale testing

Full scale testing was carried out to assess the performance of the materials under real trafficking conditions. This chapter describes the testing and analysis of the results.

7.1 Equipment used

7.1.1 SkReDeP / SCRIM

The main aim of this work is to identify materials that could be used primarily with SCRIM. To this end SkReDeP was used as the primary device for measuring the skid resistance properties of the candidate surfaces. In order that the full scale testing can be conducted in an efficient a manner as possible, three other SCRIMs were sourced from the pool of survey contractors to aid in the trafficking of the surfaces.

7.1.2 GripTester and PSRT

To supplement measurements made with SkReDeP, the Highways England GripTester (Figure 7-1) was used as a second data acquisition device. GripTester is a small trailer based device for measuring low speed skid resistance. Its use is defined in British Standard, BS 7941-2:2000 (British Standards Institution, 2000), this procedure was used for the full scale testing.



Figure 7-1 GripTester

The measurements made with this device and the PSRT (discussed in section 5.1) were used in conjunction with those collected using SkReDeP to characterise any changes in skid resistance of the candidate surfaces. In addition measurements made using GripTester were useful in ascertaining the applicability of the surfaces for use with other skid resistance testing devices.

7.2 Trial site and surface installation

An initial site visit to the Membury airfield found the main runway to be an ideal location for the trial site. The area was found to be:

- Long enough for the vehicles to achieve the necessary test speed.
- Wide enough to allow for an easy turnaround at either end.
- An area where the flow of traffic could be effectively regulated.
- Flat and level (note observation 3 from the prototype testing).

Before testing, the surface was installed in the configuration shown in Figure 7-2. Retro-reflective markers were used to allow the automatic insertion of markers at the start and end of the test section. The test section could therefore be identified accurately in the results. Figure 7-3 shows the installation and testing of the reference surfaces.

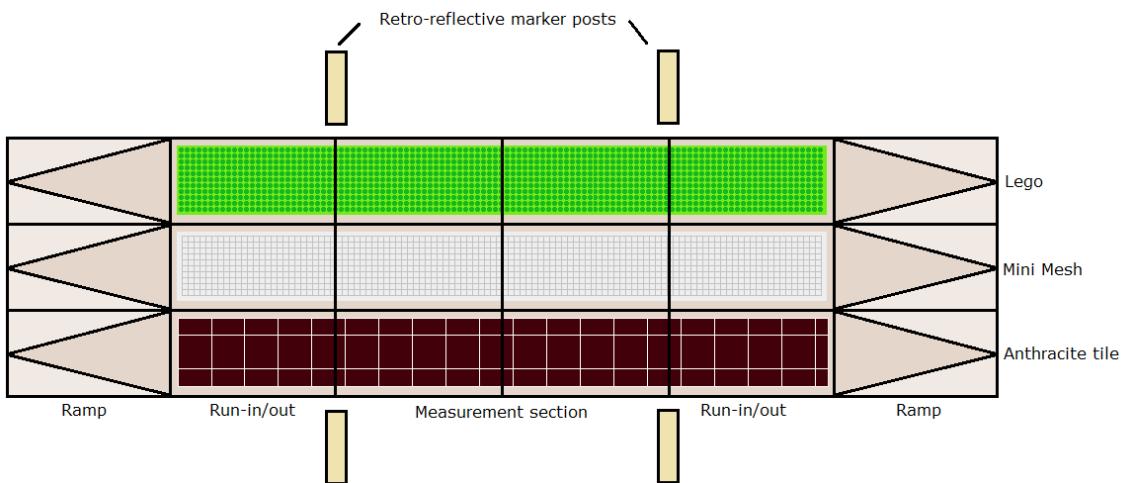


Figure 7-2 Layout of test surfaces (not to scale)



Figure 7-3 Installation of the surfaces (above), Setting up of PSRT (left) and trafficking with SCRIM devices

7.3 Testing regime

The testing procedure for this study can be summarised as follows:

- Each test surface was “trafficked” by four SCRIM vehicles, including SkReDeP, for a minimum of 180 passes.
- Measurements of skid resistance were made with SkReDeP, GripTester and the PSRT. SkReDeP was part of the fleet of trafficking vehicles and so made measurements every four passes. The PSRT and GripTester were used to make measurements after; 0, 12, 40, 100 and 180 passes.
- It was endeavoured to make measurements with the same tyre / PSRT foot to improve the repeatability of measurements.
- Supplementary measurements of skid resistance were also made with one of the other trafficking vehicles.
- Measurements made using SkReDeP utilized a retro-reflective marker system to accurately identify the reference surfaces in the results.
- Lego and anthracite tiles were tested, alternating between each surface after every pass, as in Figure 7-4.

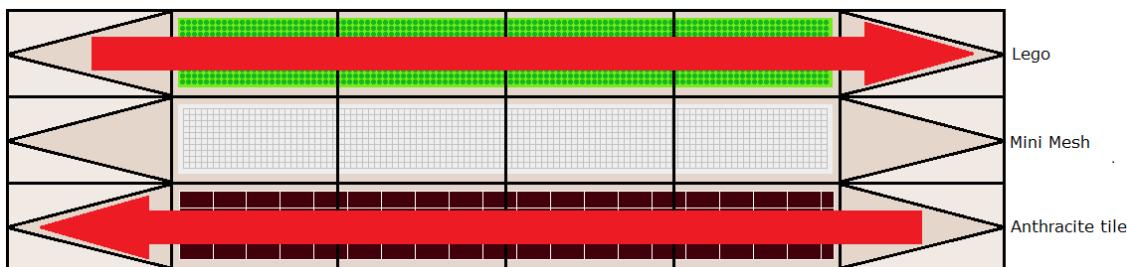


Figure 7-4 Trafficking surface 1 and 2

- At the end of this stage of testing, the Lego surface was moved next to the Anthracite tile surface, allowing measurement of the Mini mesh, as in Figure 7-5.

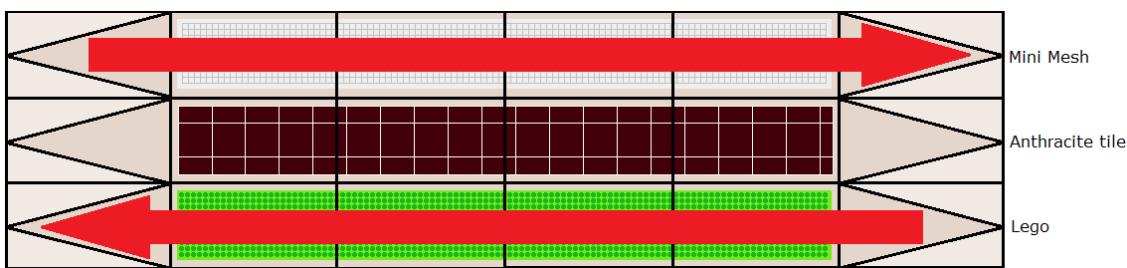


Figure 7-5 Trafficking surface 1 and 3

- Throughout the testing an adjacent section of the existing runway (a 6 mm thin surface course system) was measured with SkReDeP to act as a control.

8 Results of full scale testing

This chapter presents the analysis carried out on the results gathered from the full scale testing. Although SkReDeP was the primary measurement device for the full scale testing, measurements were made with other devices. Analysis of results collected from all devices was carried out and is presented in this chapter to answer the following questions in the flow chart given in Figure 4-1. Is the friction level acceptable? Does the material polish or wear with use?

8.1 Skid resistance development platform

Results gathered using SkReDeP are shown in Figure 8-1, for comparison, information collected at the 2014 AAT has also been included. The point markers in Figure 8-1 represent the measurements made with SkReDeP, and the solid lines represent the lines of best fit for these surfaces. For clarity the individual measurements made at the 2014 AAT have been omitted, the broken lines represent the lines of best fit of the measurements made at the AAT.

The skid resistance levels on the Lego and Mini-mesh surfaces is well within the required range of 0.1 to 1.0 SC(50), which translates to 12.8 to 128.2 SR⁹. The friction level on the tile surface is below this range and therefore outside of the normal SCRIM operating range.

At the flattest parts of their curves the Mini-mesh and Lego surfaces are providing similar levels of skid resistance to the Transverse grooved concrete and Smooth asphalt concrete used at the AAT respectively.

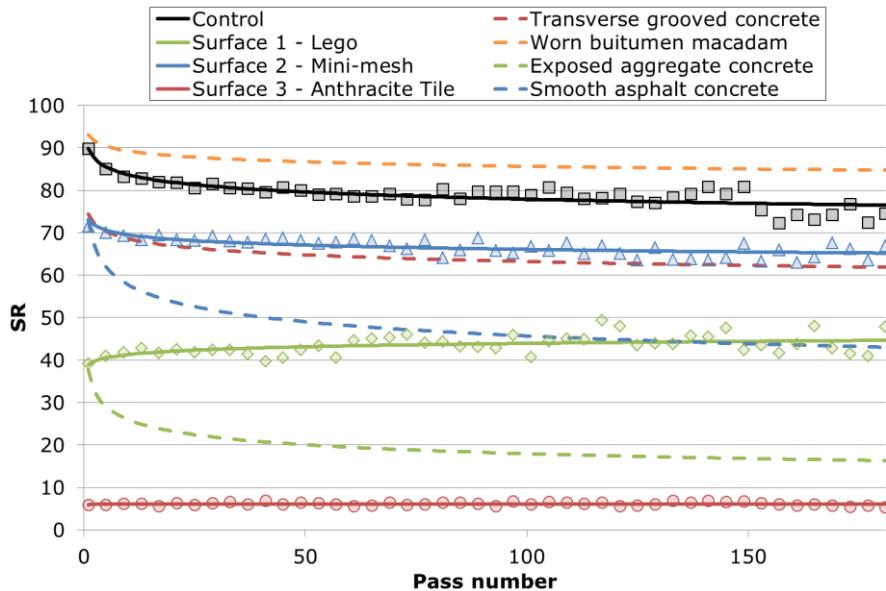


Figure 8-1 Change in skid resistance (SCRIM) under progressive testing

⁹ Conversion using index of SFC: $SC = SR / 100 * 0.78$

The material showing the most desirable performance, the flattest curve, is the Anthracite tile. The greatest rate of change is shown by the exposed aggregate concrete used at the AAT. The rate of change of the candidate materials is markedly lower than that of two of the surfaces used at the AAT, and the control section measured as part of the full scale testing. However the Performance of the transverse grooved concrete is similar to that of the Mini-mesh and Lego, the worn bitumen macadam shows less change in skid resistance than these surfaces.

8.2 Grip tester and Portable skid resistance tester

The GripTester and PSRT measurements (Figure 8-2 and Figure 8-3 respectively) similarly show some evidence of a change in skid resistance. With a smaller number of measurements made with these devices, the confidence in the exact shape of the trends is lower, but the scale of the change observed is smaller than that measured with SkReDeP.

The absolute skid resistance values for the GripTester and SkReDeP measurements on the reference surfaces are similar but, while the measurements made with the PSRT follow the same overall pattern, the measurements made with the PSRT on the tile surface are substantially greater than those made with GripTester and SkReDeP.

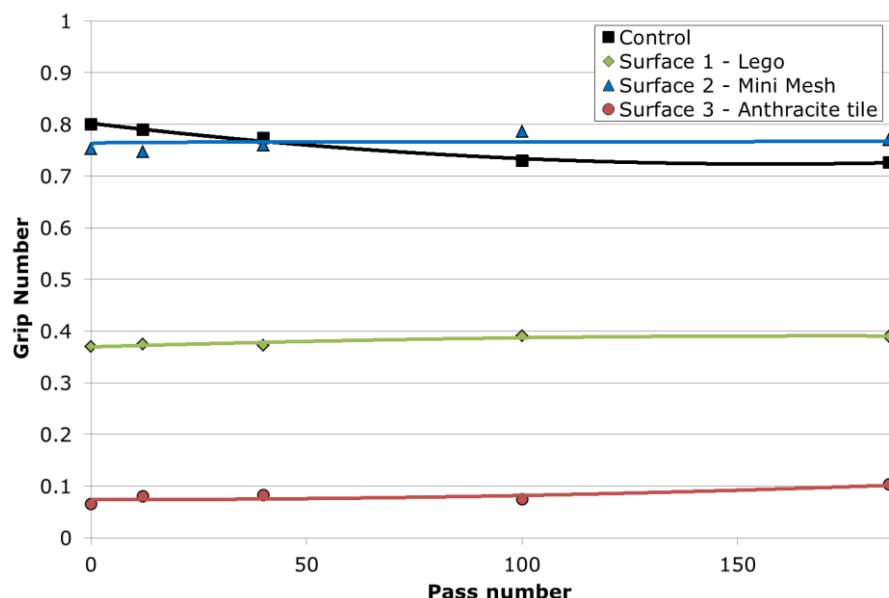
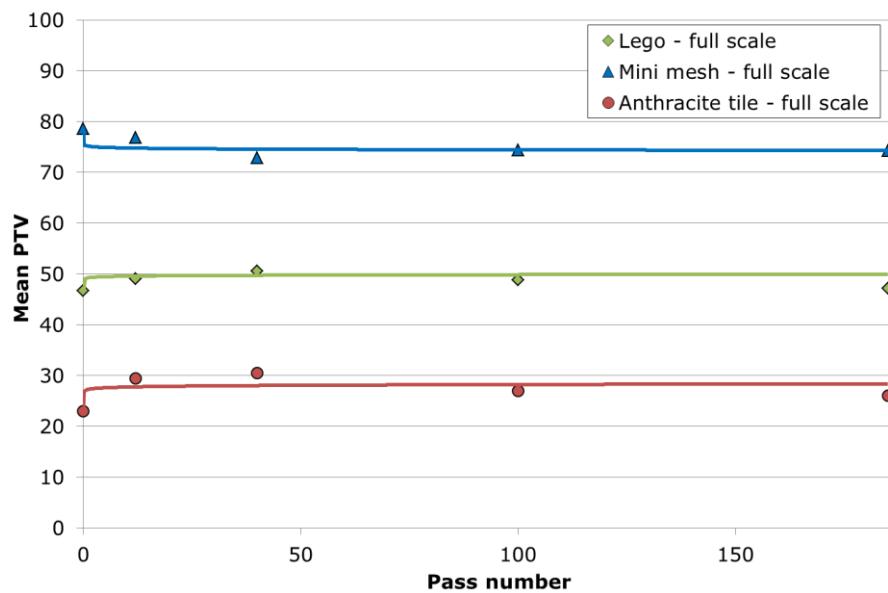


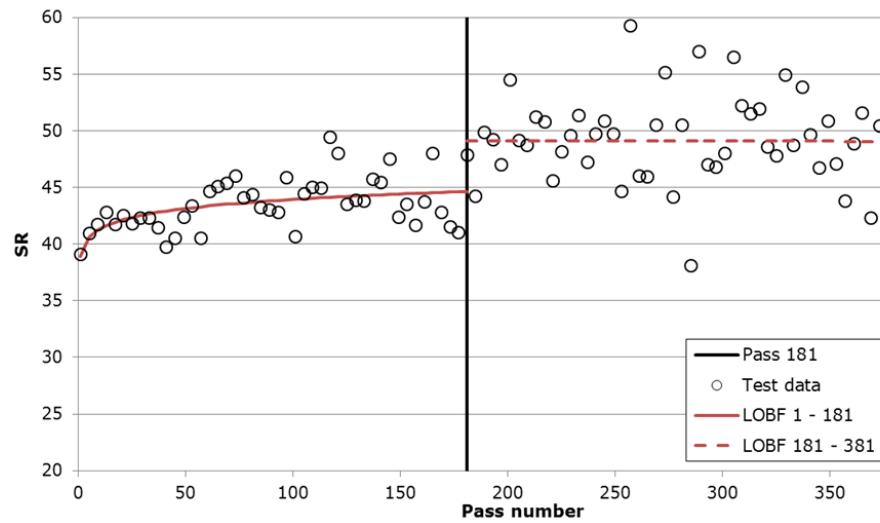
Figure 8-2 GripTester measurements

**Figure 8-3 PSRT Full scale measurements**

8.3 Other observations

8.3.1 Behaviour of Lego surface after 181 passes

An interesting observation in the results on the Lego surface was a marked change in performance after 181 passes. Figure 8-4 shows that the skid resistance values measured after this point has increased by approximately 8 SR, additionally the variation in performance has also increased.

**Figure 8-4 Lego results to 381 passes**

The reason for this change in performance is not clear but could be related to the following factors relating to the trial activities after 181 passes:

- The Lego section was moved next to the tile section to allow the trafficking of the Mini-mesh section. This caused the Lego section to be trafficked in the opposite

direction. It is possible therefore that the trafficking before 181 passes had changed the shape of the surface in such a way as to affect the measurements made in the opposite direction.

- The test tyre used was swapped to allow the Mini-mesh section to be trafficked with a new tyre. It is possible, although unlikely, that the change in performance could be related to differences in tyre characteristics. If this were the case it would be expected to also see changes in the control section, which were not identified.
- The Mini-mesh section was trafficked, this appeared to have a smoothing effect on the test tyres. This could have also altered the skid resistance measurement on the Lego section. But, a smoother tyre would be expected to reduce the friction measurement, and these effects would also be expected to be observed on the control section.

8.3.2 Detailed SR measurements

For the analysis of results from the full scale testing the raw data output from SkReDeP was used. Raw data is collected at approximately 10 cm intervals and so gives a high resolution representation of the forces acting on the SCRIM tyre. Figure 8-5 shows the profile of skid resistance, vertical load and horizontal load values measured across the 4.8 m of the Anthracite tile measurement section.

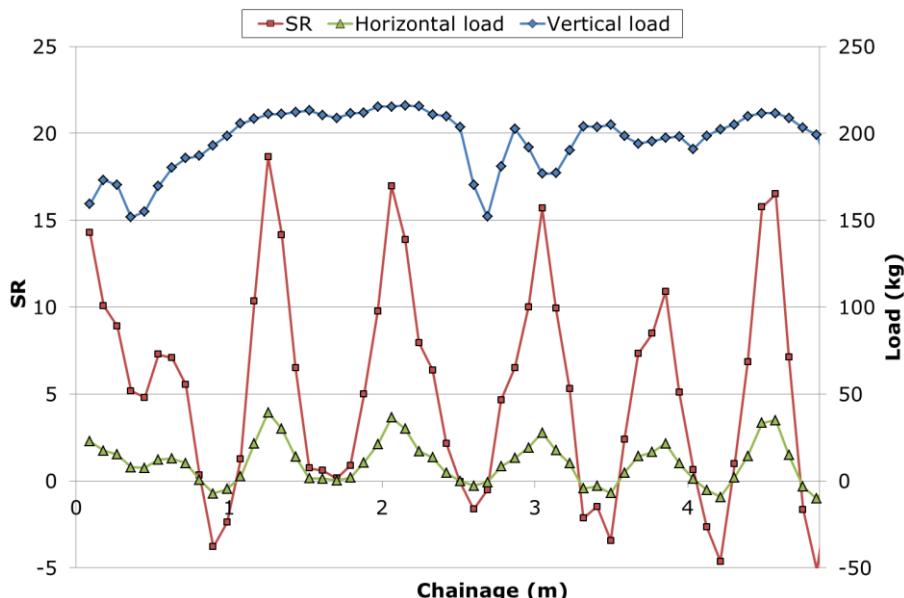


Figure 8-5 Anthracite tile, Pass 1, SkReDeP Raw data

Here it can be seen that the profile follows a pattern of peaks and troughs with a wavelength of approximately 0.8 m. The majority of the troughs are showing negative SR values associated with negative measurements of horizontal load. This is believed to be a consequence of the apparent oscillation in the horizontal force combined with a very low level of friction. It was not investigated within the scope of this project.

8.3.3 *Movement of surface with trafficking*

During the course of the full scale testing a small amount of movement was observed on the reference surface. The surface appeared to rotate by approximately 0.4° from the initial direction of travel. Within the scope of the full scale testing this was negligible but this should be considered if longer surfaces are to be used in the future.

9 Practical application of reference materials

The results from Chapter 8 have shown that the performance of the materials tested at the full scale trial are, on the whole, superior to those used at the AAT. The advantages of adopting a skid resistance reference surface are outlined in chapter 1. This chapter explores the potential options for the use of the reference surfaces assessed for the accreditation of SCRIM devices.

9.1 Application scenarios

The assessment of the applicability of the candidate materials relies, in some part, on the procedure under which they will be used. The two main scenarios for the use of the reference materials for accreditation of the SCRIM fleet are discussed here:

- The whole SCRIM fleet is accredited simultaneously at a single annual trial.

The benefit of this scenario is that variations in skid resistance occurring from test tyres and surface conditioning can be reduced through the trial procedure. The limitations are that the logistics involved are complex owing to the requirements for gathering the SCRIM fleet in one place for the three days of the trial. This approach gives a snapshot of the status of the fleet on the day of testing, the performance of the fleet throughout the year is not verified under this procedure.

- The individual machines are accredited separately.

This methodology is similar to that used for the accreditation road condition assessment vehicles (Pavement Condition Information Systems, 2009). The advantages of this methodology are that the implementation costs and logistical barriers are reduced. This provides the opportunity for assessing vehicles more than once per year, improving the confidence in the results collected. A limitation of this technique is that surface conditioning effects will more difficult to account for than in the first scenario.

Since the performance requirements for the second scenario are more demanding, in terms of requiring a consistent level of skid resistance throughout the working life of the reference surface, this was selected for further analysis. For the purpose of assessing the suitability of the reference materials the following working assumptions were made about the accreditation scenario, as listed in Table 9-1.

Table 9-1 Assumptions for the assessment of surface application

Assumption	Justification
The number of machines that a surface should be able to accredit is 40.	The current UK SCRIM fleet consists of 18 machines, but on occasion extra machines take part in AATs for research purposes. The AAT procedure often requires a re-accreditation to be carried out on the fleet should machines require alteration.
The length of the surface to be measured is 120 m.	Some of the devices in the SCRIM fleet are only capable of reporting measurements to a resolution of 10 m. Discounting the first and last 10 m of the surface will allow for 100 m of the surface to provide valid measurements.
Number of valid test runs per machine is 5.	This is as per the current trial methodology and is, listed in Table 2-1 as the appropriate number of runs to be carried out on a 100 m long reference surface.

9.2 Distribution of results

The assessment of the practical application of the reference materials requires some statistical analysis of the results. In order to carry out statistical analysis, it is important to ascertain how the results are distributed. A normal distribution would allow the use of standard statistical tools.

The challenge in assessing the distribution of skid resistance results lies in the changing nature of skid resistance with measurement. Therefore to directly test the distribution of skid resistance results at, say, 100 test passes is impossible. Estimating the distribution of measurements can be achieved by analysing the distance of individual measurements from the line of best fit, using the procedure detailed below:

- Lines of best fit were calculated for the initial assessment of surface performance (reported in Chapter 8). The lines of best fit that gave the best correlation with the measurements were based on power functions ($y = a \times x^b$).
- The constants defining the lines of best fit were generated by transforming the measurements onto a log scale by taking the natural logarithm of the measurements, this transformation is shown in Figure 9-1. This produced a linear relationship ($y = mx + c$) from which the gradient (m) was calculated by dividing the change in values on the y axis by the change in values on the x axis. The y-axis intercept (c) was calculated by extrapolating the line to the y-axis and taking the value at intersection.

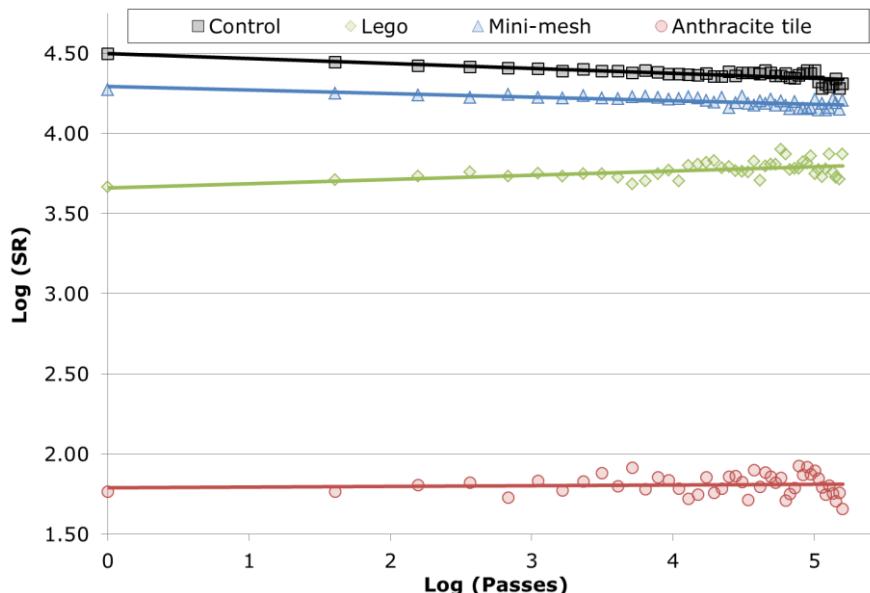


Figure 9-1 Natural logarithm of skid resistance measurements

- The m and c values were then converted back to a linear scale using the relationships below:

$$a = e^c \text{ and } b = m$$

Where:

e = the base of the natural logarithm

Equation 9-1 Calculation of line of best fit constants

- This allowed the calculation of the distance of each point from the line of best fit by using Equation 9-2.

$$d_p = SR_p - (a \times p^b)$$

Where:

P = The pass number of the value being assessed.

d_p = The distance of the skid resistance measurement made at pass p from the line of best fit.

SR_p = The skid resistance value measured at pass number p.

Equation 9-2 Calculation of the distance of results from the line of best fit

The distribution of values from the line of best fit were plotted as a histogram, Figure 9-2. As a crude measure of normality the Skew of the distributions was calculated, this was not found to be significant¹⁰ for any of the surfaces.

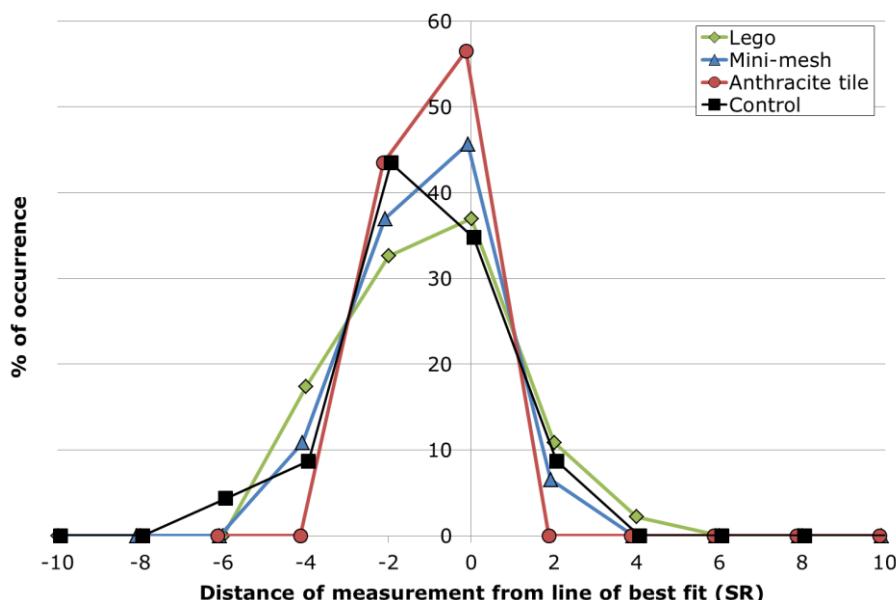


Figure 9-2 Distribution of skid resistance values from line of best fit

¹⁰ Greater than 2 times the square root of 6/the number of points

A full normality test was then carried out by calculating the Cumulative Distribution Factor (CDF) and the expected values, based on the CDFs. The expected values were then compared with the actual values, this is shown in Figure 9-3.

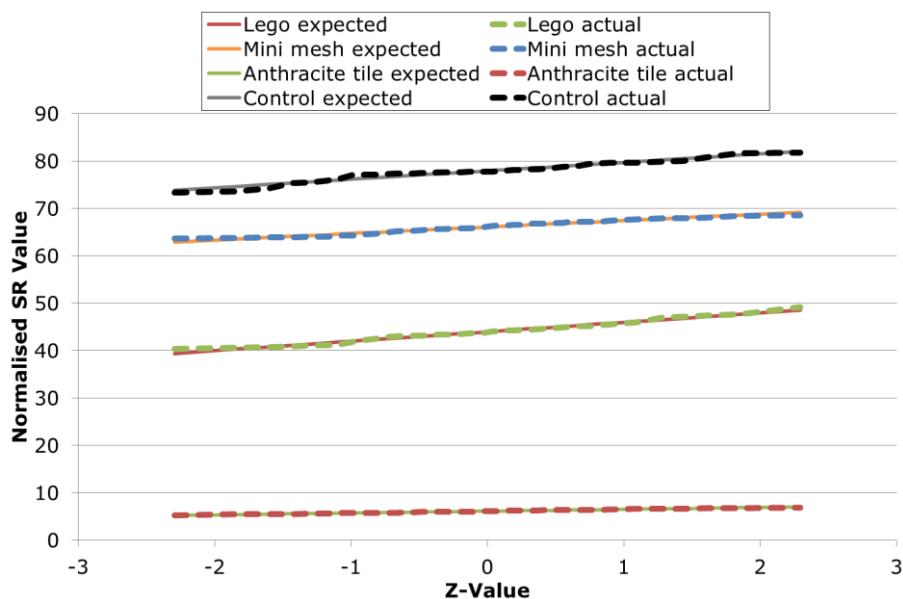


Figure 9-3 Normality test for residual results

Here it can be seen that the actual values are very similar to the expected values. It is therefore concluded that statistical tools requiring a normal distribution are applicable for the analysis.

9.3 Practical assessment of material properties

With the exception of the tile surface, an observation of the full scale testing was that the skid resistance performance shows a relatively large initial change followed by progressively smaller changes. The practical assessment of materials will therefore focus on the point at which the rate of change in skid resistance is sufficiently small for it to be useful as a reference surface.

9.3.1 Calculation of statistical properties of surfaces

The analysis of the surface properties was based on the statistical properties of the results collected at the full scale trial, namely:

- The line of best fit (described in section 9.2),
- Standard deviation of measurements,
- The expected measurement confidence interval.

The measurements collected at the full scale trial were used to calculate these properties. The use of the properties of the results, and not the individual results, allows the extrapolation of the measurements beyond those made at the full scale trial. This enables a hypothetical longer term case to be tested.

9.3.1.1 Standard deviation of measurements

The standard deviation of measurements (STDEV) was carried out by calculating the square root of the average relative position of measurements from the line of best fit, as per Equation 9-3.

$$STDEV = \sqrt{\frac{\sum_{p=1}^{p=181} |SR_p - (a \times p^b)|}{n}}$$

Where:

n = the number of measurements made.

p = pass number.

SR_p = the skid resistance value at pass number p.

a and b = the constants describing the line of best fit.

Equation 9-3 Calculation of the standard deviation of measurements

9.3.1.2 Expected measurement confidence interval

The expected measurement confidence interval was based on the range of the confidence limit for each surface. This was calculated using Equation 9-4.

$$R = \frac{2T \times STDEV}{\sqrt{Pe}}$$

Where:

- R = the range of the confidence interval.
- STDEV = the standard deviation calculated from Equation 9-3.
- Pe = The number of equivalent passes required at the full scale trial to measure 500 m of surfacing.
- T = two-tailed inverse of the Student's t-distribution with 95% confidence and 48 degrees of freedom.

Equation 9-4 Calculation of measurement confidence range

The calculation of the measurement confidence range requires the consideration of the second and third assumptions listed at the start of this chapter. The combination of these assumptions results in a single machine measuring 500 m of surface for accreditation. The length of the reference surfaces used at the full scale trial were approximately 5 m, for 500 m of each surface to have been measured at the full scale trial 100 measurement passes would have therefore been required.

This range was then applied to the line of best fit to produce an upper and lower measurement confidence interval band for each surface. An example of this is shown for the control surface in Figure 9-4.

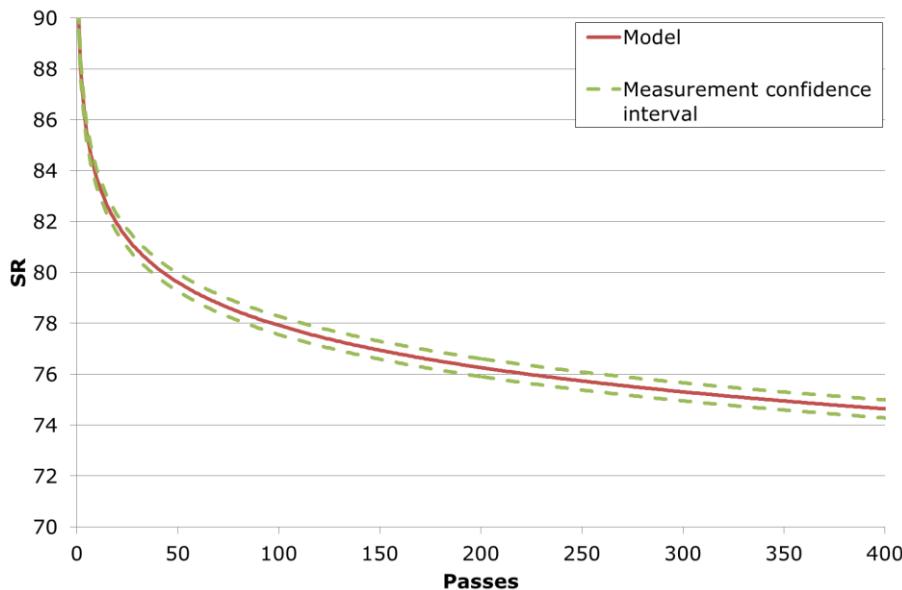


Figure 9-4 Control measurement confidence intervals

9.3.2 Calculation of wear in period and working window

The wear in period is defined as the amount of initial polishing required until the expected change in skid resistance in the working window is within acceptable limits. Likewise the working window is defined as the amount of trafficking that a material may be exposed to before the change in skid resistance exceeds acceptable limits.

The wear in period and working window are therefore variables that are dependent on one another. In the interest of pragmatism it was necessary to define a fixed value to either the wear in period or working window. The working window was therefore defined as 200 passes¹¹. In order to calculate the wear in period for each surface it is also necessary to define acceptable limits for the change in skid resistance in the working window. This analysis is carried out with the application of accrediting SCRIMs in mind, the terminology used reflects this.

Acceptable limits for the change in skid resistance within the working window were based on the confidence interval (CI) for the five measurements made at the extremes of the working window. This represents the expected spread in measurements made by the first and last machines to be accredited, machine 1 and machine 40.

The current standard for SCRIM accreditation is reported in the Pavement Condition Information Systems guidelines (Pavement Condition Information Systems, 2013). This document stipulates that the between equipment standard deviation threshold for the SCRIM fleet is 2.7 SR. It was deemed prudent that this value also be used for the performance threshold for the reference surfaces.

The point at which the difference between the upper confidence interval as pass number p and the lower confidence interval after pass number $p + 200$ differed by ≤ 2.7 SR was calculated. The pass number p , is the minimum required wear in period. A worked example of this analysis is illustrated for the control surface in Figure 9-5.

¹¹ This figure was derived from the assumptions that a reference surface should be able to accredit 40 machines, each making 5 passes

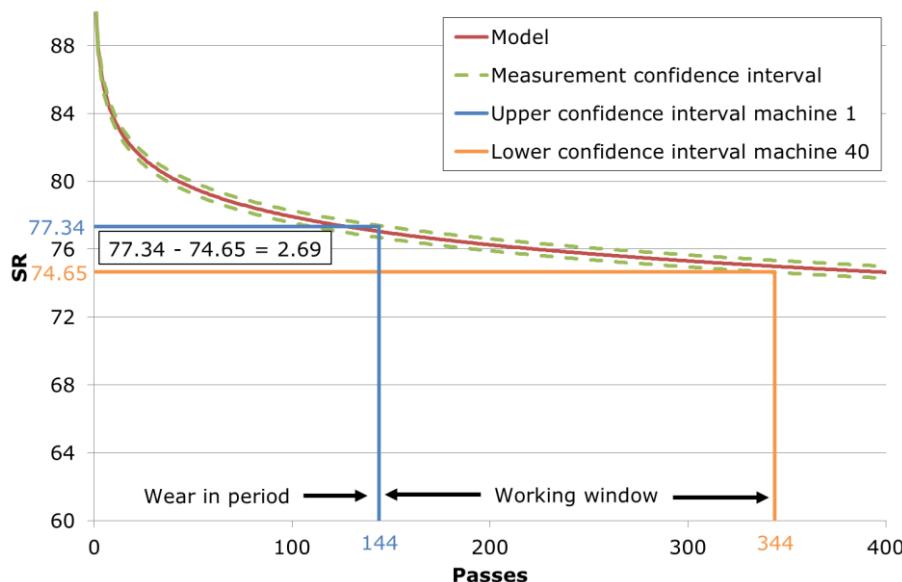


Figure 9-5 Example of wear in period calculation for control surface

9.3.3 Calculation of acceptable machine performance requirements

In order to use the reference surfaces to accredit SCRIMs, acceptable machine performance criteria must first be derived. Two possible performance criteria are given below, the benefits and limitations of each is listed. Both performance criteria are based on the current criteria laid out in the PCIS guidelines for SCRIM accreditation (Pavement Condition Information Systems, 2013). This document states that:

"Equipment that deviates by more than 3 times the BESD¹² criterion from the all-Equipment mean will be rejected. Any Equipment that is between two and three times the BESD criterion from the all-Equipment mean will be subject to further investigation."

The application of 2 and 3 times the BESD will be used in order to apply an acceptable performance envelope to the reference surfaces.

9.3.3.1 Static criterion

The first procedure for the accreditation of devices is to use a static criterion, that would be applied to all machines being accredited. The performance requirements were calculated by adding 2 and 3 times the BESD criterion to the machine 1 upper confidence limit and subtracting these values from the machine 40 lower confidence limit. This is represented graphically in Figure 9-6.

¹² The Between Equipment Standard Deviation (BESD) criterion is ≤ 2.7 SR (Pavement Condition Information Systems, 2013)

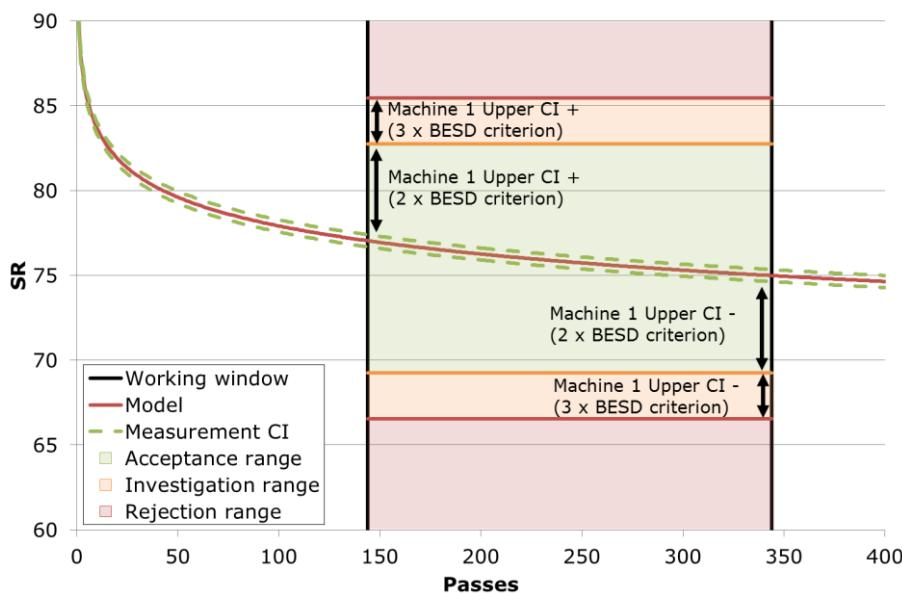


Figure 9-6 Example of static accreditation criterion for control surface

The advantage of this analysis is that the same measurement value is required of all machines, creating an unambiguous criterion. Furthermore any slight changes in surface performance between surfaces constructed in different years, or by different batches of material, has a small effect on the criterion.

The limitation of this analysis are that, as a result of the change in skid resistance with trafficking, there is a bias towards machines being accredited towards the middle of the working window. Machines making measurements in the middle of the working window will therefore be exposed to a less demanding test than machines making measurements at the extremes of the working window.

9.3.3.2 Dynamic criteria

The second procedure is to use dynamic criteria based on the amount of trafficking received by the reference surface. The dynamic accreditation ranges were calculated by adding 2 and 3 times the BESD criterion to the upper and lower measurement confidence intervals. This is represented graphically in Figure 9-7.

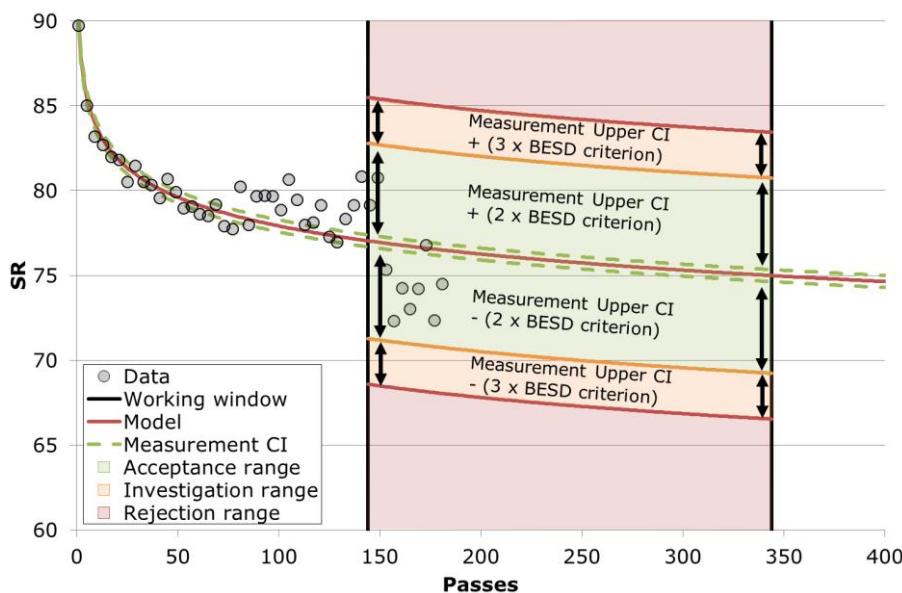


Figure 9-7 Example of dynamic accreditation criteria for control surface

The advantage of this analysis is that all machines are exposed to an equally demanding test. The limitation of this technique is that small changes in the between year/batch variation of surfaces has a greater impact on the criteria than the analysis above. Because of this limitation the confidence in the between year/batch performance of the reference surfaces should be high before adopting this technique.

From the work carried out in this project there is insufficient evidence to favour either one of the assessment procedures. Further understanding about the between year/batch performance of these surfaces will be used to identify the most appropriate of these techniques.

9.3.4 Characterisation of materials

The materials assessed as part of the full scale trial were characterised by calculating the wear in period, measurement confidence interval range and line of best fit for each surface. Results are summarised in Table 9-2 and presented graphically in Appendix D.

Table 9-2 Summary of performance of surfaces at full scale trial

Surface	Wear In Period (Passes)	Measurement confidence interval range (SR)	Line of best fit ($y=ax^b$)	
			a	b
Control	144	0.71	89.880	-0.031
Surface 1 – Lego	45	0.79	38.873	0.027
Surface 2 – Mini-mesh	55	0.54	73.203	-0.022
Surface 3 – Anthracite Tile	0	0.15	5.986	0.005

10 Assessment of candidate materials

This chapter assesses each of the candidate materials with reference to the flow chart shown in Figure 4-1. The assessment is carried out with a view to using the candidate materials for SCRM accreditation, some discussion regarding the use of the materials with other devices is given in Chapter 11.

10.1 Lego

10.1.1 Initial assessment

10.1.1.1 Is the friction level acceptable?

The indicative skid resistance values for the measurements made within the working window this surface was approximately 0.35 SC(50), this is within the requirement for the reference surface.

10.1.1.2 Does the material polish or wear with use?

The initial laboratory measurements for this surfacing were promising; the range of PTVs measured in the laboratory was within the repeatability of the PSRT. The results from the full scale testing showed an increase in skid resistance with trafficking. However the calculated wear in period was 68 passes which is practically achievable within one day using one machine.

10.1.1.3 Is the material robust and water resistant?

The application as a reference surface is an unusual one for this material, nonetheless the material is strong, and water resistant. Under full scale conditions the material held up well to the trafficking. However towards the end of the testing it was evident that water had accessed the adhesive/surface interface making some modules unstable and caused them to debond from the surface. It is envisioned that these issues could be overcome with further development.

10.1.1.4 Can the material be stored without changing?

It is unlikely that the material will be affected from environmental conditions, such as rust or corrosion. If the surface is stored in an environment where the surface remains unscratched or damaged then it is likely that the material could be stored for extended periods of time without changing.

10.1.2 Can the material be used as a long term system?

10.1.2.1 Is the material produced consistently?

The laboratory assessments were carried out on three specimens of the material, sourced from different manufacturing batches. The results from these assessments showed a range of PTVs between the specimens of 1.2. This result is promising but this question may only be answered with further, more extensive, full scale testing.

Confidence in the repeatability of this material can however be fairly high, Lego products are produced to a tolerance of 0.002 m and after a series of quality assurance tests the

rejection rate of all Lego products is 0.00002% fail (Wilson, 2006). These tolerances apply only to the dimensions of the product, it is unknown as to how tightly the material composition is controlled.

10.1.2.2 Is the material recyclable or disposable in landfill?

ABS plastic can be easily recycled, so disposal in landfill of the material shouldn't be necessary. However if an adhesive is used to attach the panels to the supporting engineering then the surface may require disposal in landfill.

10.1.3 Implementation assessment

10.1.3.1 Could the material produce multiple friction levels?

It may be possible to design a similar material with a different surface profile, however this is unlikely to alter the material properties significantly as the microtexture of the surface will remain unchanged. Furthermore if the microtexture of the surface is changed the stability of the skid resistance would require further investigation.

10.1.3.2 Is the material cost effective?

The cost of the material is the greatest of all the materials assessed at £91.20/m², the full scale testing has shown that this surface would be able to last the duration of a single AAT before requiring replacing.

Using 120 m x 1 m of the material at an AAT, the cost of the surface would be £10,944.00 per trial. However, given the quantity of material required to produce a surface to these dimensions, there may be scope for the application of an economy of scale, or for an alternative supplier to be identified.

10.1.3.3 Could the material be used in a portable system?

The application of this material is dependent on the supporting engineering. It is feasible that a system could be designed, similar to that used in the full scale testing to allow the surfaces to be transported and installed on any suitable trial site.

10.1.4 Conclusion

This material could be used as a reference surface for SCRIMs with the caveat that the correct wear in period is carried out before reference measurements are made.

The cost of using this surface as part of an AAT is significant, however, it may be possible to achieve an economy of scale when using the amount of material required for a full AAT.

10.2 Mini-mesh

10.2.1 Initial assessment

10.2.1.1 Is the friction level acceptable?

The indicative skid resistance values for the measurements made within the working window this surface was approximately 0.51 SC(50), this is within the requirement for the reference surface.

10.2.1.2 Does the material polish or wear with use?

The initial laboratory measurements for this surface were promising; the 90th percentile range of PTV values were within the repeatability of the PSRT.

The results from the full scale testing showed a decrease in skid resistance with trafficking. However the wear in period for this surface was within acceptable limits.

An observation made during the full scale testing was that the voids in the surface became filled with water during the testing. It could therefore be possible that the reductions in skid resistance measured were in part related to the saturation of the surface with water. Some further investigations into this effect may be warranted.

10.2.1.3 Is the material robust and water resistant?

The main application of this material is as decking for docks and marinas, an assumption could therefore be that the material has been designed with water resistance in mind. The full scale testing showed that the material performed very well under trafficking.

10.2.1.4 Can the material be stored without changing?

The components of this system are based on materials that are unsusceptible to environmental changes. It is therefore likely that the material can be stored for a reasonable amount of time, without a significant change in skid resistance.

10.2.2 Can the material be used as a long term system?

10.2.2.1 Is the material produced consistently?

The laboratory assessments were carried out on three specimens of the material, sourced from different manufacturing batches. The results from these assessments showed a range of PTVs between the specimens of 4.2. This result is promising but this question may only be answered with further, more extensive, full scale testing.

10.2.2.2 Is the material recyclable or disposable in landfill?

GRP materials may be recycled, but facilities to do so are only available in Germany. So in practical terms this surface would be disposed of in landfill.

10.2.3 Implementation assessment

10.2.3.1 Could the material produce multiple friction levels?

This particular product is based on one grade of surfacing material, however it is plausible that a similar system could be developed to generate multiple friction levels.

10.2.3.2 Is the material cost effective?

The cost of the material is £47.55/m², the full scale testing has shown that this surface would be able to last the duration of at least a single AAT before requiring replacing. However, if the results from prolonged use were favourable then the surface may be able to be used for multiple trials.

If 120 m x 1 m of the material were to be used at an AAT the cost of the surface would be £5,706.00 per trial.

10.2.3.3 Could the material be used in a portable system?

The application of this material is dependent on the supporting engineering. It is feasible that a system could be designed, similar to that used in the full scale testing to allow the surfaces to be transported and installed on a suitable trial site.

10.2.4 Conclusion

This material could be used as a reference surface for SCRIMs with the caveat that the correct wear in period is carried out before reference measurements are made.

Although lower than that of the Lego surface, the cost of using this surface as part of an AAT is high. Further testing may however demonstrate that the performance of the surface is valid for multiple trials, reducing the cost per trial.

10.3 Anthracite tile

10.3.1 Initial assessment

10.3.1.1 Is the friction level acceptable?

The indicative skid resistance performance within the working window for this surface was approximately 0.05 SC(50), this is lower than the lower requirement of 0.1 SC(50). But when used in conjunction with other surfaces would be beneficial for assessing the sensitivity of machines to detecting low skid resistance levels.

10.3.1.2 Does the material polish or wear with use?

The initial laboratory measurements for this surfacing showed the best performance of all candidate materials. The results from the full scale testing showed that there is almost no change in skid resistance with trafficking.

10.3.1.3 Is the material robust and water resistant?

The usual application of the material is as a floor tile for use in kitchens and bathrooms. The material is therefore designed for use in wet conditions. Ceramic materials are naturally quite brittle and unless the material is suitably supported there may be an issue with cracking.

During the full scale testing some cracking was observed on a single tile, but it is believed that this was due to a loose stone being impacted by the vehicle tyres. Under normal use it could be expected for the surface to last multiple AATs.

10.3.1.4 Can the material be stored without changing?

If stored inside, it is unlikely that the material will be affected by normal environmental conditions. If the surface is stored in an environment where the surface remains unscratched or damaged then it is likely that the material could be stored for extended periods of time without changing.

10.3.2 Can the material be used as a long term system?

10.3.2.1 Is the material produced consistently?

The laboratory assessments were carried out on three specimens of the material, sourced from different manufacturing batches. The results from these assessments showed a range of PTVs between the specimens of 1.6. This result is promising but this question may only be answered with further, more extensive, full scale testing.

10.3.2.2 Is the material recyclable or disposable in landfill?

No information could be found to show that there is a common technique for recycling ceramic tiles, other than re-using reclaimed materials. It is likely therefore that this material will be disposed of as construction rubble.

10.3.3 Implementation assessment

10.3.3.1 Could the material produce multiple friction levels?

The assessment of other ceramic tiles as part of the laboratory testing showed that other tile types are not capable of maintaining their skid resistance values with trafficking. No other suitable candidates were identified through this work.

10.3.3.2 Is the material cost effective?

The cost of the material is £19.95/m², the full scale testing suggested that this surface would be able to last the duration of multiple AATs before requiring replacing.

If 120 m x 1 m of the material were to be used at three consecutive AATs, the cost of the surface would be £2,394.00 per trial.

10.3.3.3 Could the material be used in a portable system?

The application of this material is dependent on the supporting engineering. It is feasible that a system could be designed, similar to that used in the full scale testing to allow the surfaces to be transported and installed on a suitable trial site.

10.3.4 Conclusion

The performance of this material with trafficking was encouraging, however, nominal performance of this surface is outside of the normal operating range of SCRIM. To this end it would be unadvisable to use this surface without the use of two other surfaces within the normal operating range of SCRIM.

11 Discussion and conclusions

This chapter discusses the results of the study in more detail, and presents the implications of the results gathered. Conclusions are made based on the findings, and the further knowledge required before the reference materials could be used practically is discussed.

11.1 Implementation of reference materials for SCRIM accreditation

The full scale testing has shown that the surfaces can potentially be used as reference surfaces for assessing SCRIMs. The surfaces could be implemented using either of two scenarios; a whole fleet accreditation, or single machine accreditation.

For the whole fleet accreditation scenario, the change in skid resistance with polishing on these surfaces has been shown to be lower than that of the majority of surfaces currently used as part of the AAT. They would provide, with the use of the derived wear in periods, a more stable surface than those currently used. This will ensure a more robust test for the SCRIM fleet as the scatter in results introduced from surface variation will be reduced, making it easier to identify outlying machines.

Currently single machine accreditations are not carried out on the SCRIM fleet. There are a number of reasons for this; a substantial one is that the changing nature of the surfaces used for accreditation make this option unfeasible. If this could be addressed by the use of reference surfaces, single machine accreditation may be a realistic option in the future. The benefits of this scenario include:

- A reduction the time needed for testing an individual machine, and therefore less disruption to survey contractors.
- A reduction in the cost of robust mid-year accreditations, enabling monitoring of the SCRIM fleet during the survey season. This is in line with the strategy used for other road surface assessment devices, and would improve the confidence in the machine fleet.

The results of the full scale trial have demonstrated the potential for the accreditation of single machines. Before proceeding with their use, it would be necessary to demonstrate that stable skid resistance measurements can be maintained over an extended period of time by storing and periodically replacing the surfaces, and also to establish the reference friction values for each surface that will represent 'ground truth'. This work should consider the associated conditions for maintaining stable skid resistance, e.g. whether the reference surfaces need to be protected or stored inside.

The main drawback to the use of the reference materials assessed as part of this study is cost. The cost of manufacturing and installing the materials assessed is considerable. However with economies of scale and some re-design of the supporting engineering it may be possible to bring the costs down to a reasonable level.

11.2 Use of reference materials with other devices

An observation made as part of this study was that the performance of the reference materials appeared to differ when measured with SkReDeP and the other devices (GripTester and PSRT). This could be a result of the devices measuring fundamentally different characteristics of surface performance.

To demonstrate the fundamental differences in measurement between the devices, Figure 11-1 shows a typical relationship between wheel slip and friction¹³. The broken lines represent the slip percentages used by each of the devices to determine skid resistance. It can be seen that each device uses a different part of the slip / friction curve to determine skid resistance. GripTester measures skid resistance closer to the peak of the curve and the PSRT at 100% slip. Measuring skid resistance at these extremes of the curve may produce different results than measuring at 35% slip as SCRIM.

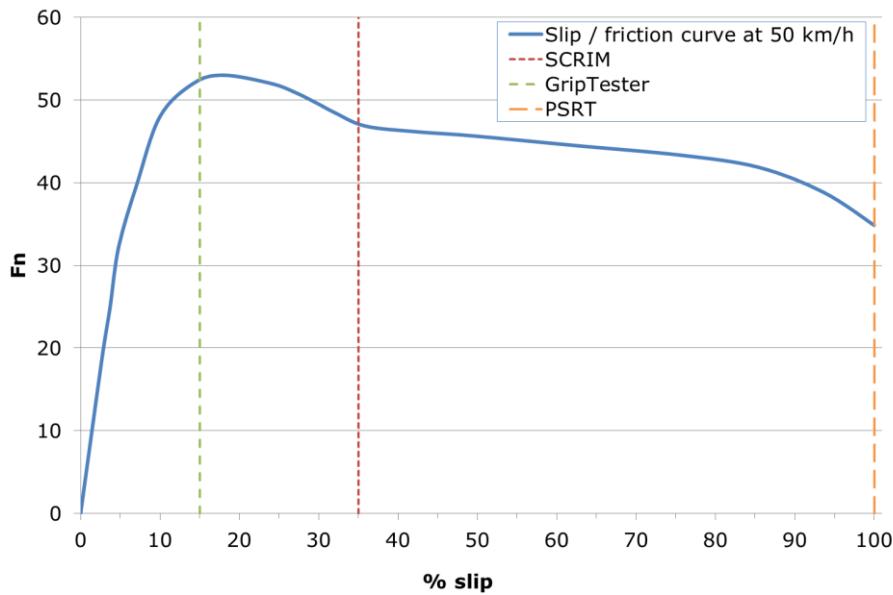


Figure 11-1 Device positions on slip / friction curve

Furthermore, GripTester and PSRT are longitudinal measurement devices, that is, measurements of skid resistance are made in the direction of travel. SCRIM uses the side-force principle making measurements at 20 degrees to the direction of travel. This is another fundamental difference in measurement and its effect on skid resistance measurement is not fully understood.

11.3 Additional knowledge required for implementation

The scope of this work was to assess the feasibility of defining a reference surface for SCRIMs, and to develop a specification which would allow this to take place. A number of questions remain that were outside this scope, and, a number of other questions have arisen from this study, as follows:

11.3.1 **What is the reference skid resistance associated with each of the reference surface materials?**

A 'ground truth' level of skid resistance needs to be established for each reference surface; this will provide the reference level against which individual machines can be

¹³ Measured using the pavement friction tester to ASTM E274 (ASTM, 2011)

assessed. While this could be determined from SkReDeP measurements, it would be more robust to take a more representative UK fleet average value to ensure continuity with current measurements.

11.3.2 *What are the wear in periods of surfaces currently used at the AAT?*

The reference surface materials have shown themselves to be more stable after particular wear in periods have been achieved. Applying a similar method to determine the wear in periods required for the surfaces used at the AAT would help to optimise the measurements to be made at the AAT.

11.3.3 *What is the long term performance of the reference materials?*

A limitation of the current AAT procedure is that a long term comparison of the fleet of SCRIMs is not possible. Small incremental changes to the fleet may, therefore, go undetected. Removing this limitation would be valuable as the performance of the fleet could be tracked year on year. In order to achieve this, it would be necessary to ascertain the long term performance of the reference materials and the consistency of materials procured in different years.

11.3.4 *How can the reference materials be used for the accreditation of devices other than SCRIM?*

Results from full scale testing have shown that the performance of the reference materials may differ when measured using devices other than SCRIM. It would therefore be beneficial to fully assess the performance of the materials when used with other devices such as GripTester, the pavement friction tester or the PSRT.

11.4 Conclusions

From the work carried out the following conclusions can be made:

- The materials tested in the full scale trial; Lego, Mini-mesh and Anthracite floor tile, can all be used as reference surfaces for SCRIM devices, subject to the appropriate wear in periods.
- The combination of all three materials would provide a robust means of accrediting SCRIMs across their working measurement range.
- To fully implement the materials as references for SCRIM the absolute performance, and the long term performance of the materials must first be ascertained.
- In order to use these materials as references for other devices further, more detailed, measurements with those devices will be required.

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Appendix A Laboratory measurements

A.1 Calculation of scuffing tyre and SCRIM tyre contact pressure

The pressure between a SCRIM test tyre, scuffing tyre, and a flat steel plate was estimated for each device in its testing configurations. This was achieved by using a flat steel load cell, to measure the vertical load on the tyres, and pressure sensitive film, to allow the determination of tyre contact area. The results are shown in the figure below.

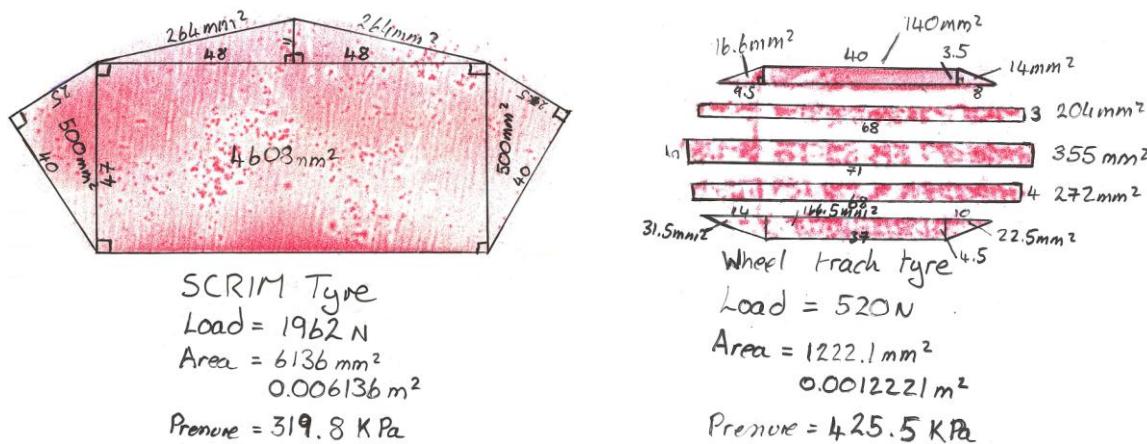


Figure A - 1 Calculation of tyre / surface contact pressure for SCRIM tyre (left) and scuffing tyre (lengths shown are in mm)

A.2 Laboratory assessment results

This section provides the results from the laboratory testing. For each material tested the pendulum test value profile is shown with cooper wheel tracker wearing. For the majority of surfaces, three specimens were tested, these are represented by the different coloured series in the figures. Below is a list of figures provided in this section and the material types that they represent:

Ceramics

- Figure A - 2 Anthracite tile
- Figure A - 3 Non-slip tile
- Figure A - 4 Graphite structured tile

Abrasive sheets

- Figure A - 6 P400 AlO paper
- Figure A - 7 P400 SiC paper
- Figure A - 8 P240 SiC paper
- Figure A - 9 P600 SiC paper
- Figure A - 10 P1200 SiC paper
- Figure A - 11 P2500 SiC paper

Resin bonded materials

- Figure A - 16 Pea gravel
- Figure A - 17 Chinese bauxite 0.9-1.4mm
- Figure A - 18 Chinese bauxite 1-3mm
- Figure A - 19 Guyanan bauxite 0.9-1.4mm
- Figure A - 20 Guyanan bauxite 1-3mm

Metals

- Figure A - 5 Diamond steel plate

Plastics

- Figure A - 12 Rolla-Trac plastic temporary flooring
- Figure A - 13 Deck Safe Mini-mesh
- Figure A - 14 Deck Safe solid panel top
- Figure A - 15

Traditional asphalt road surfacings

- Figure A - 21 10mm TSCS

Some materials have a limited number of results, this is either because the materials failed before completing the full range of polishing, or because the material was being assessed for its un-polished condition only.

A.2.1 Ceramics

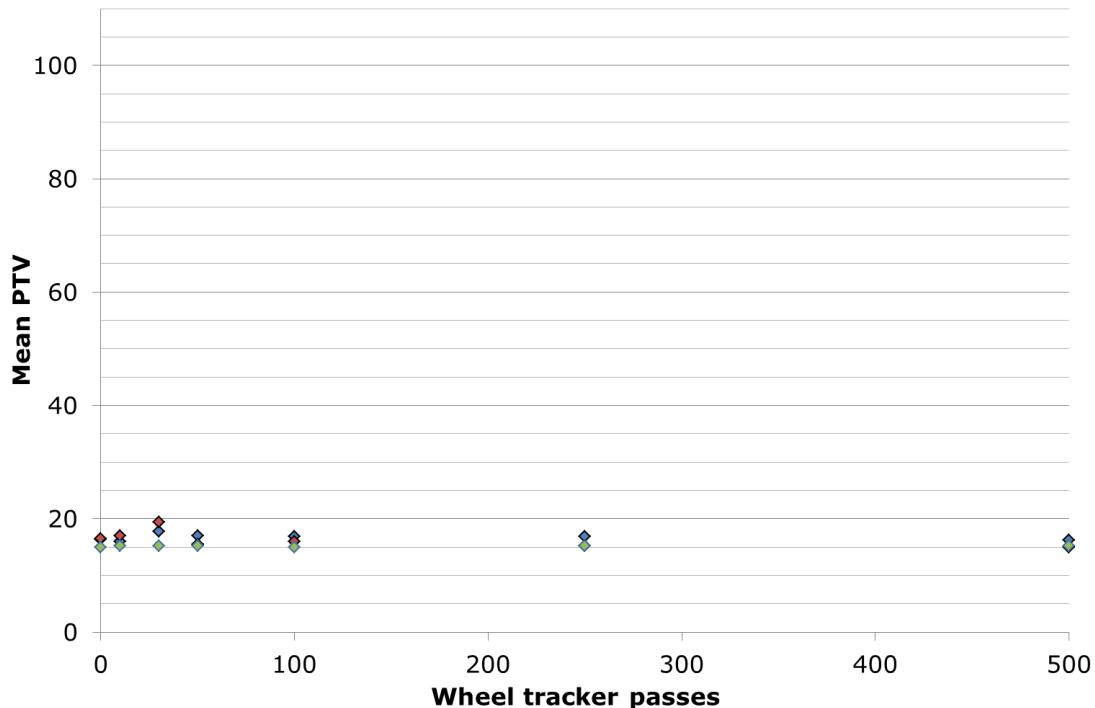


Figure A - 2 Anthracite tile

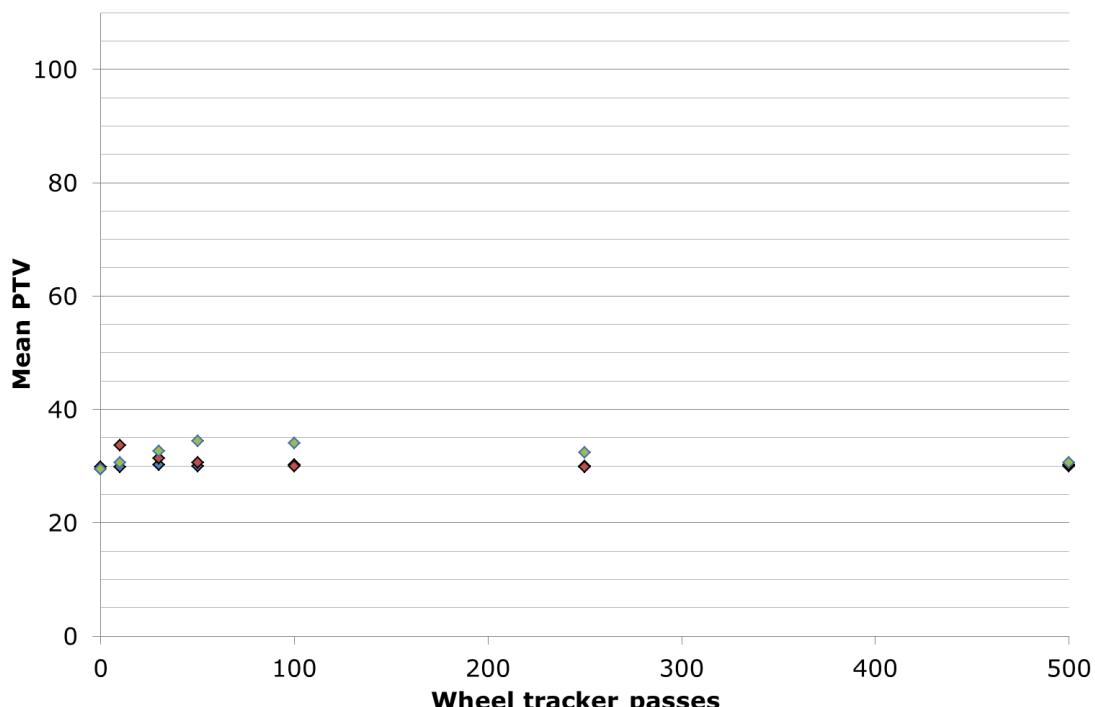
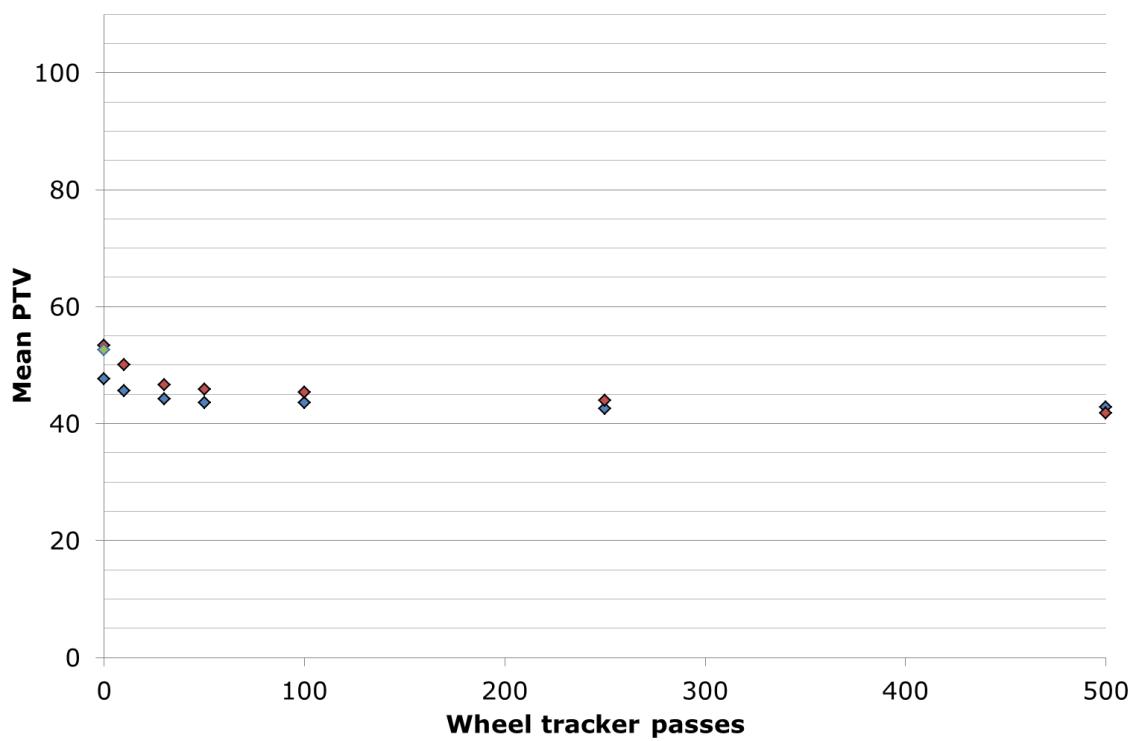
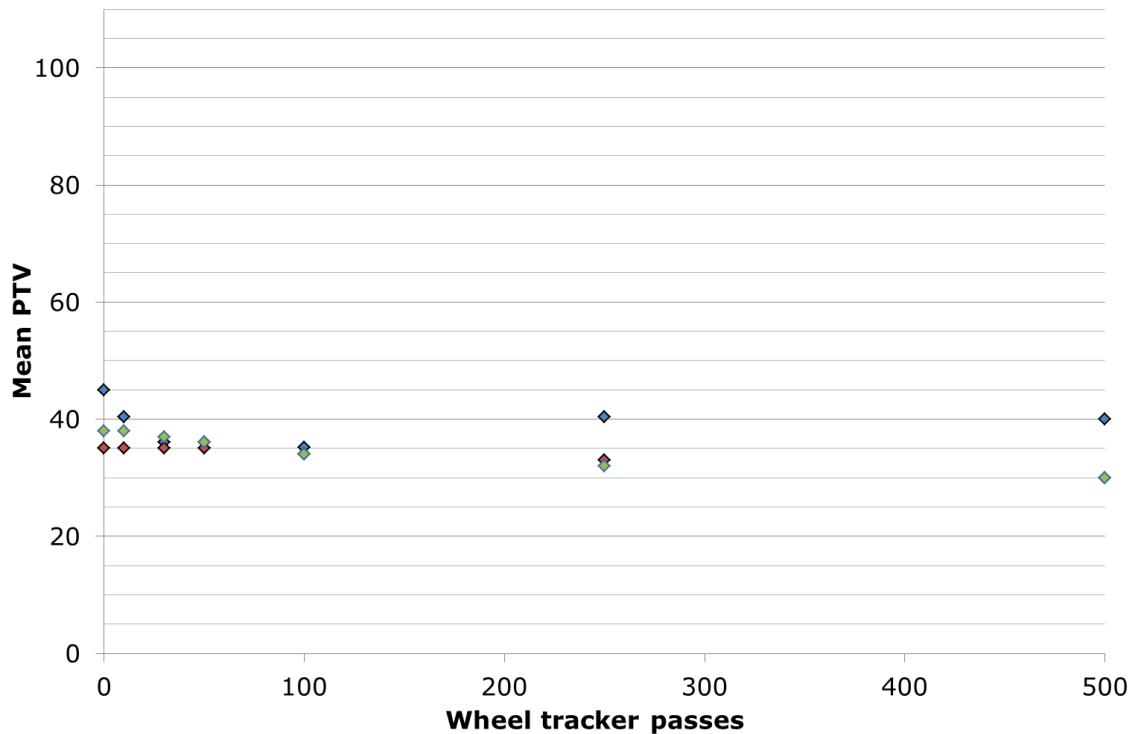
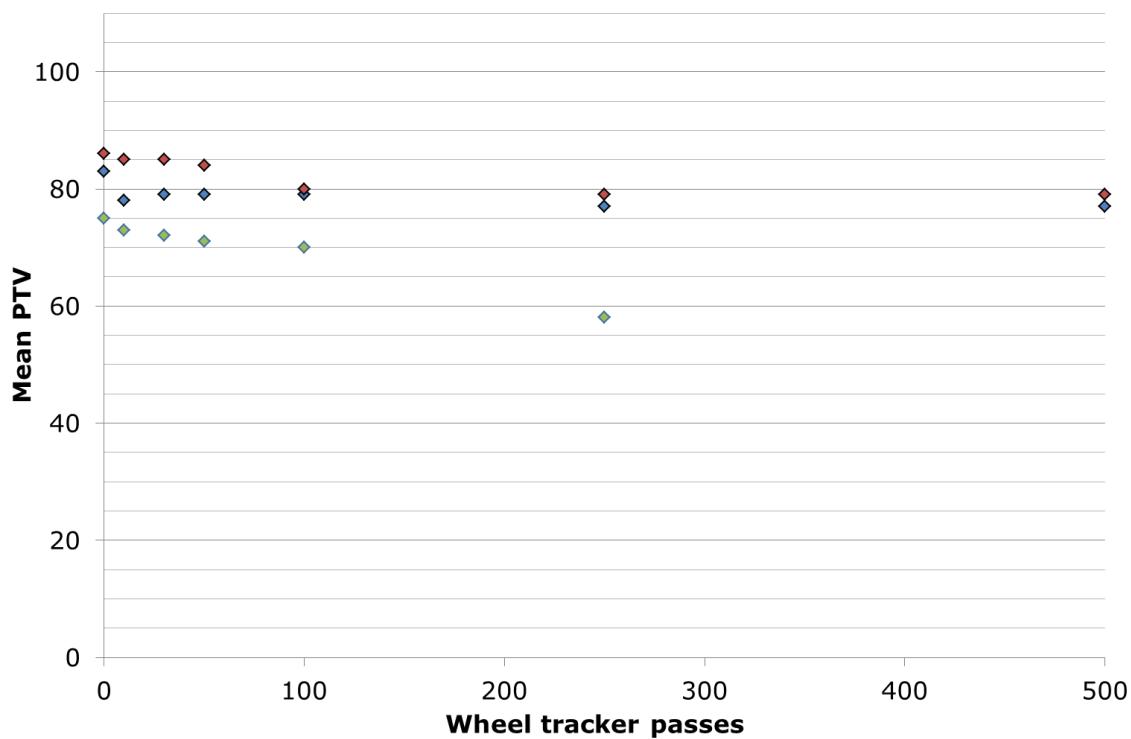
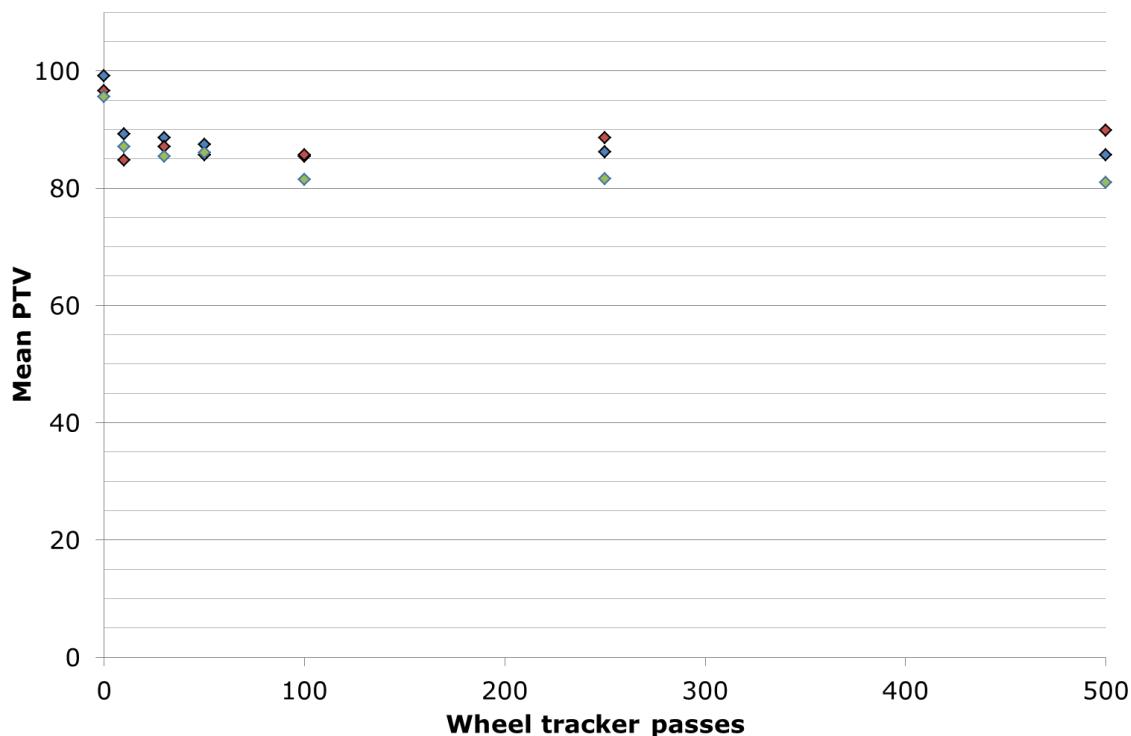


Figure A - 3 Non-slip tile

**Figure A - 4 Graphite structured tile**

A.2.2 Metals

**Figure A - 5 Diamond steel plate**

A.2.3 Abrasive sheets**Figure A - 6 P400 AlO paper****Figure A - 7 P400 SiC paper**

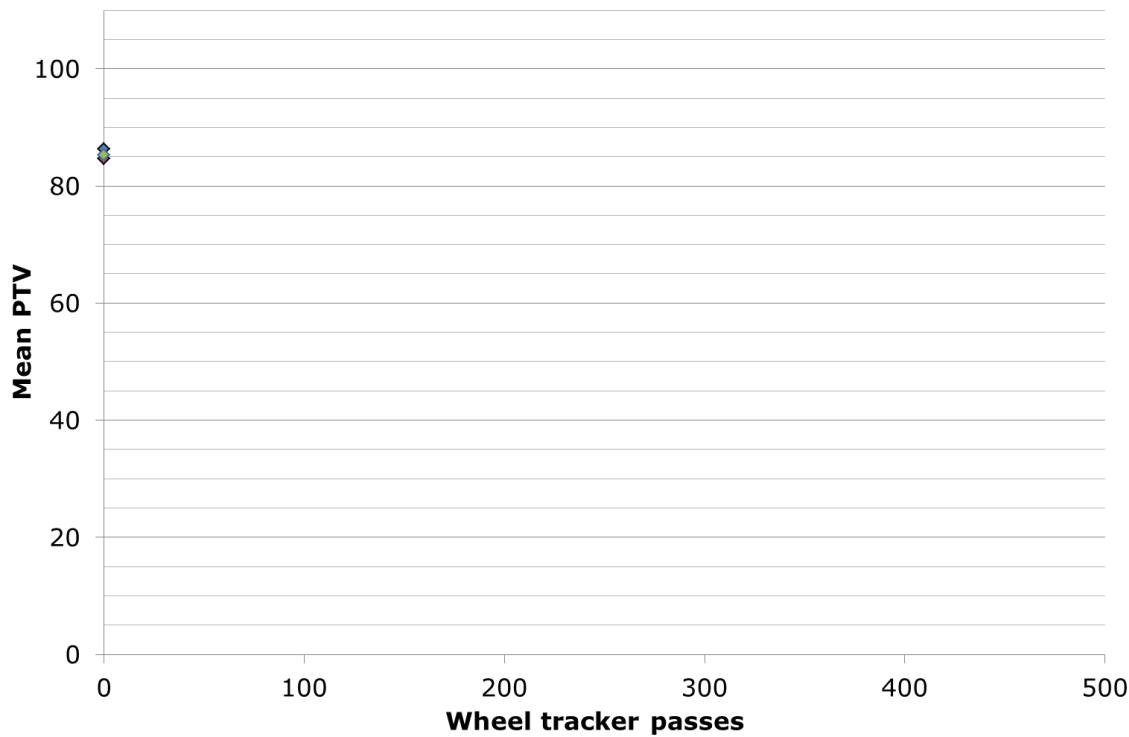


Figure A - 8 P240 SiC paper

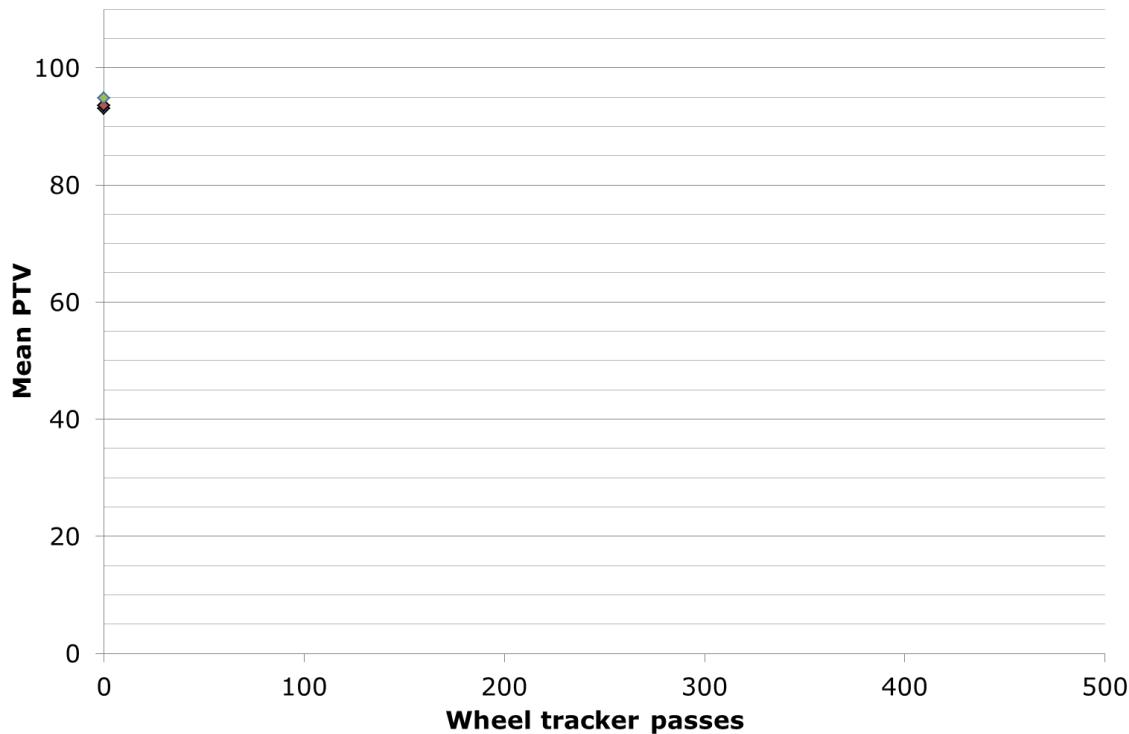


Figure A - 9 P600 SiC paper

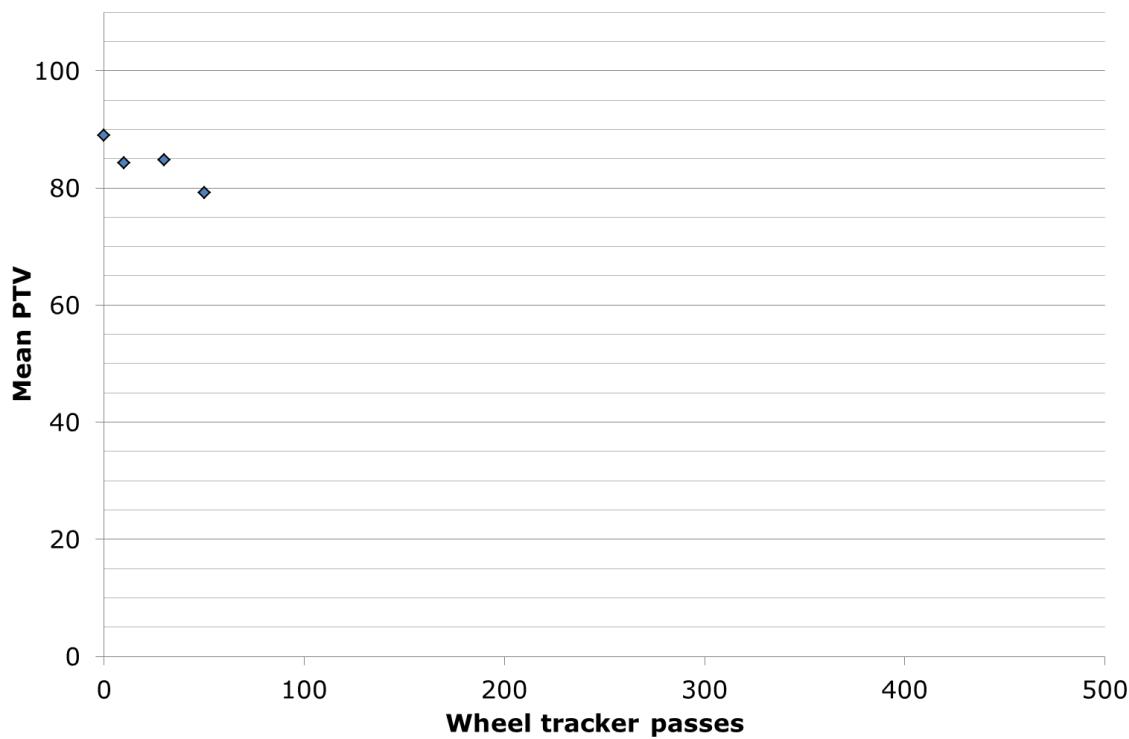


Figure A - 10 P1200 SiC paper

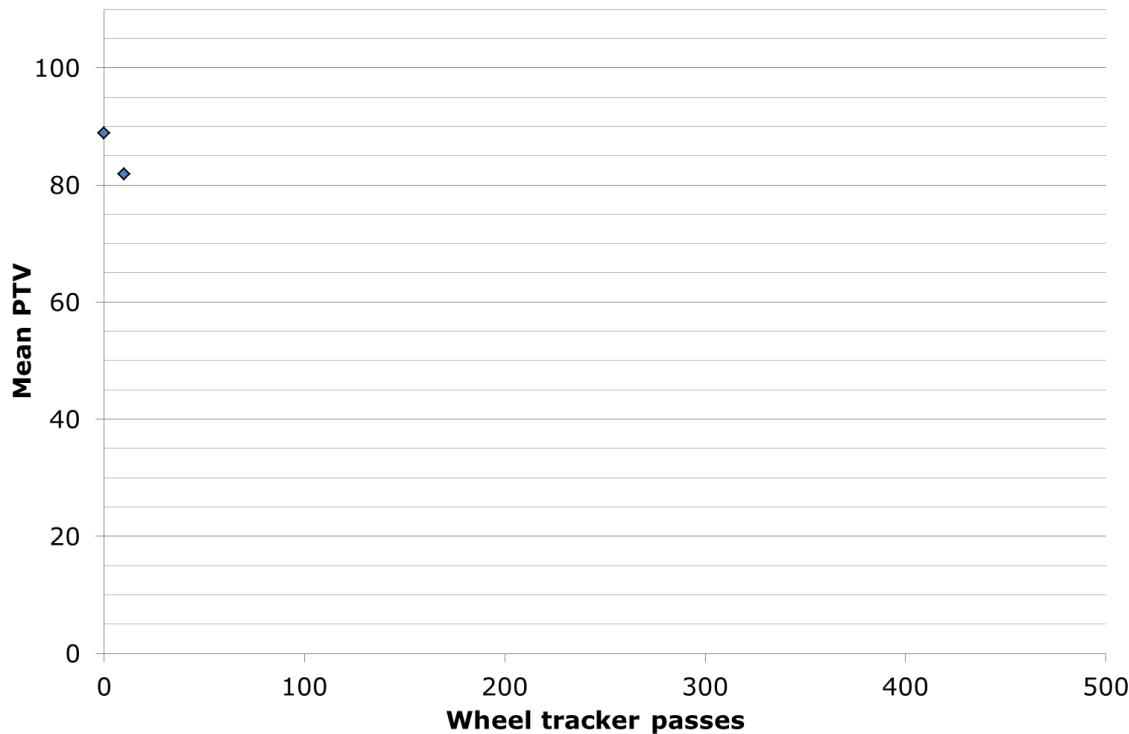
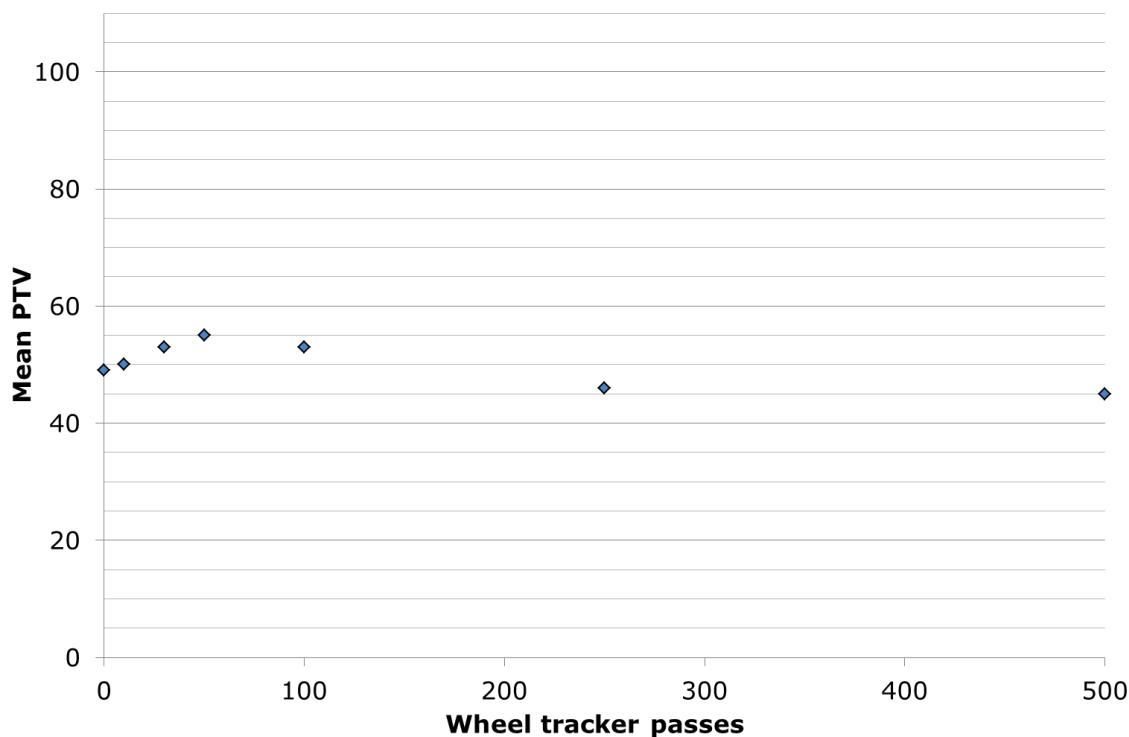
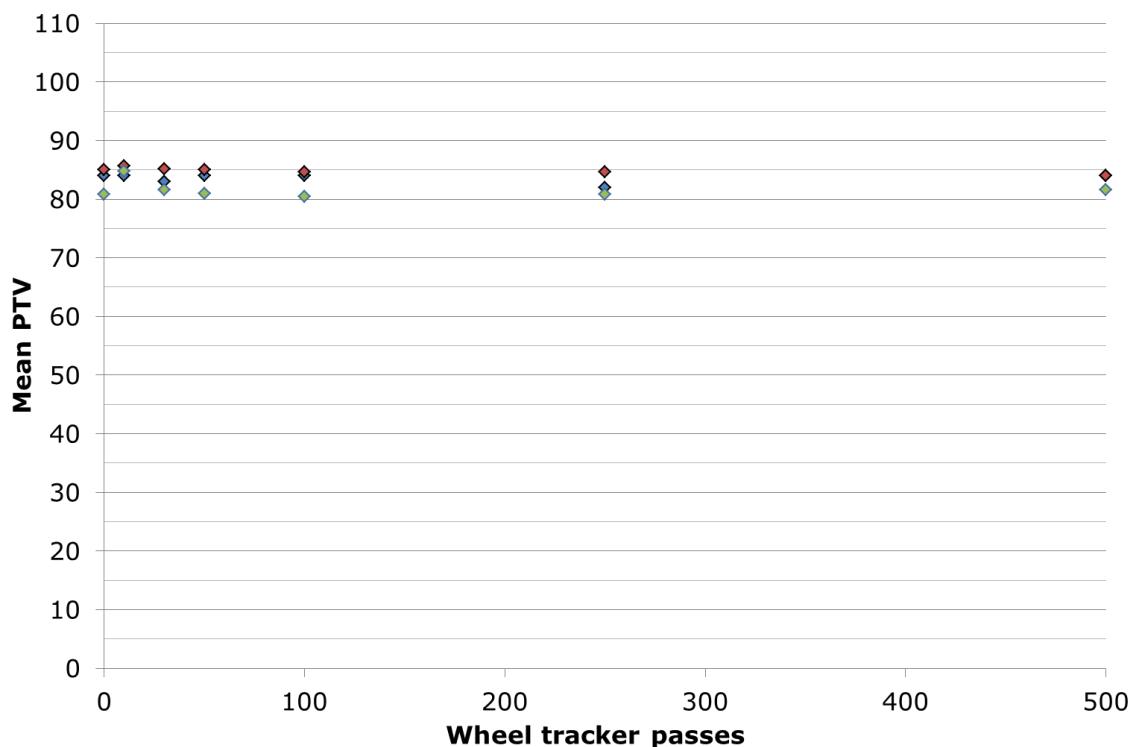


Figure A - 11 P2500 SiC paper

A.2.4 Plastics**Figure A - 12 Rolla-Trac plastic temporary flooring****Figure A - 13 Deck Safe Mini-mesh**

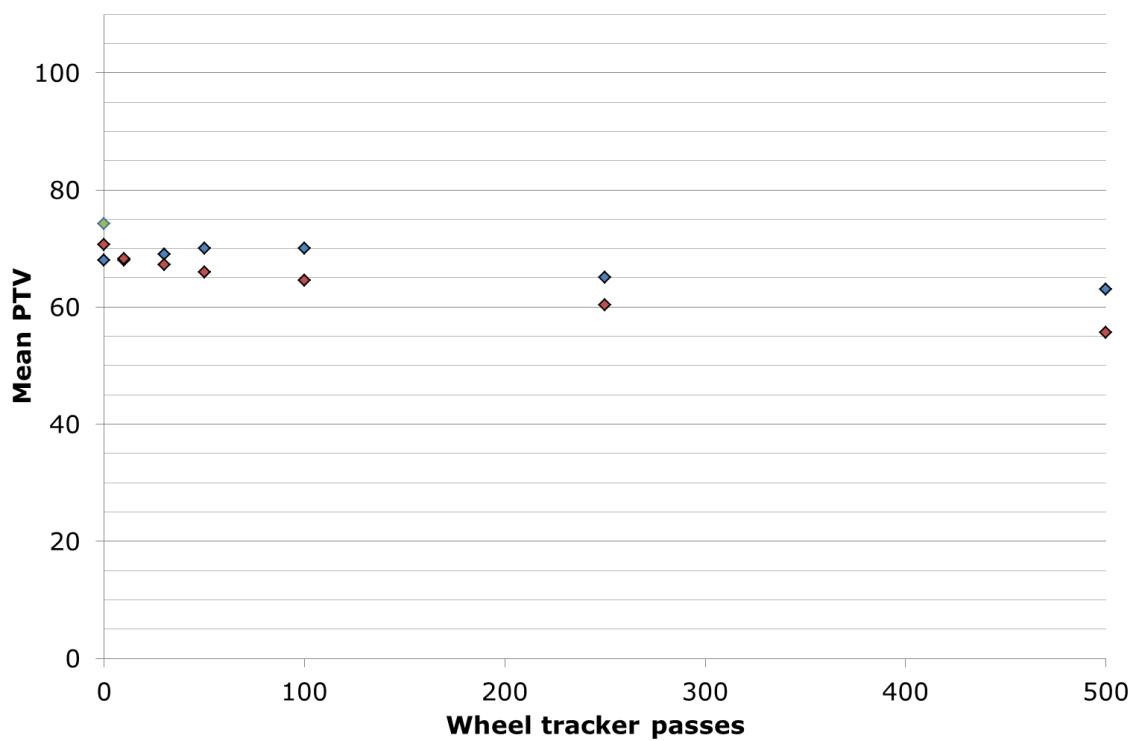


Figure A - 14 Deck Safe solid panel top

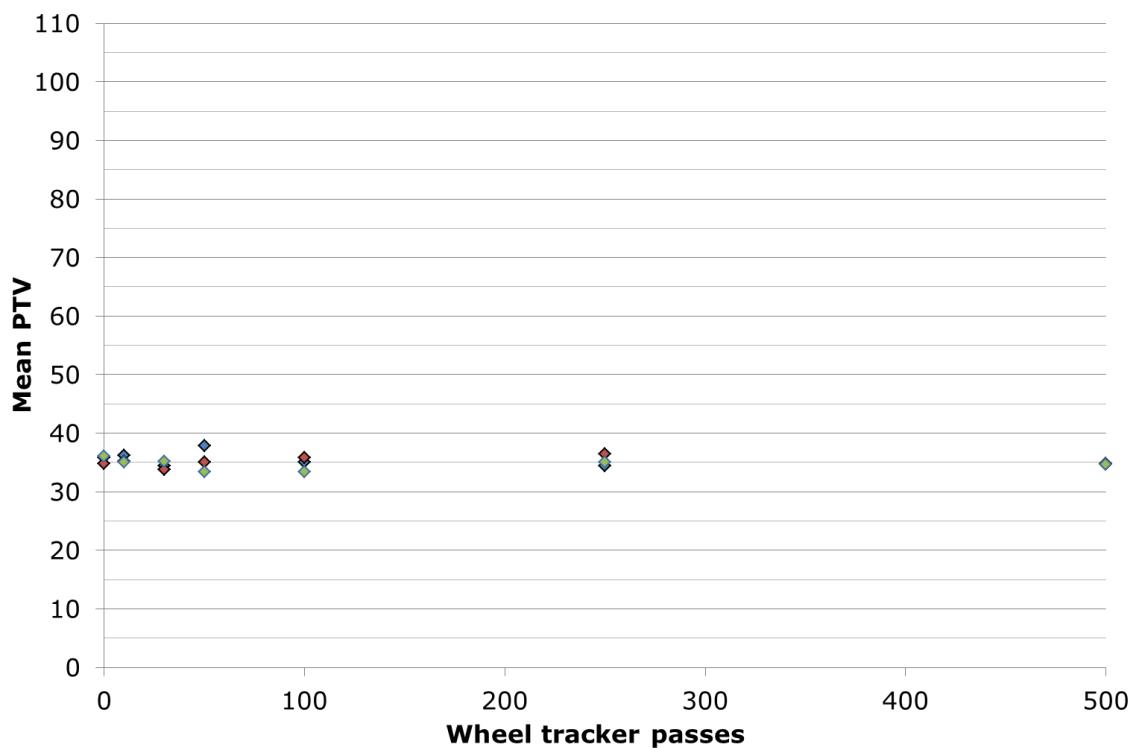
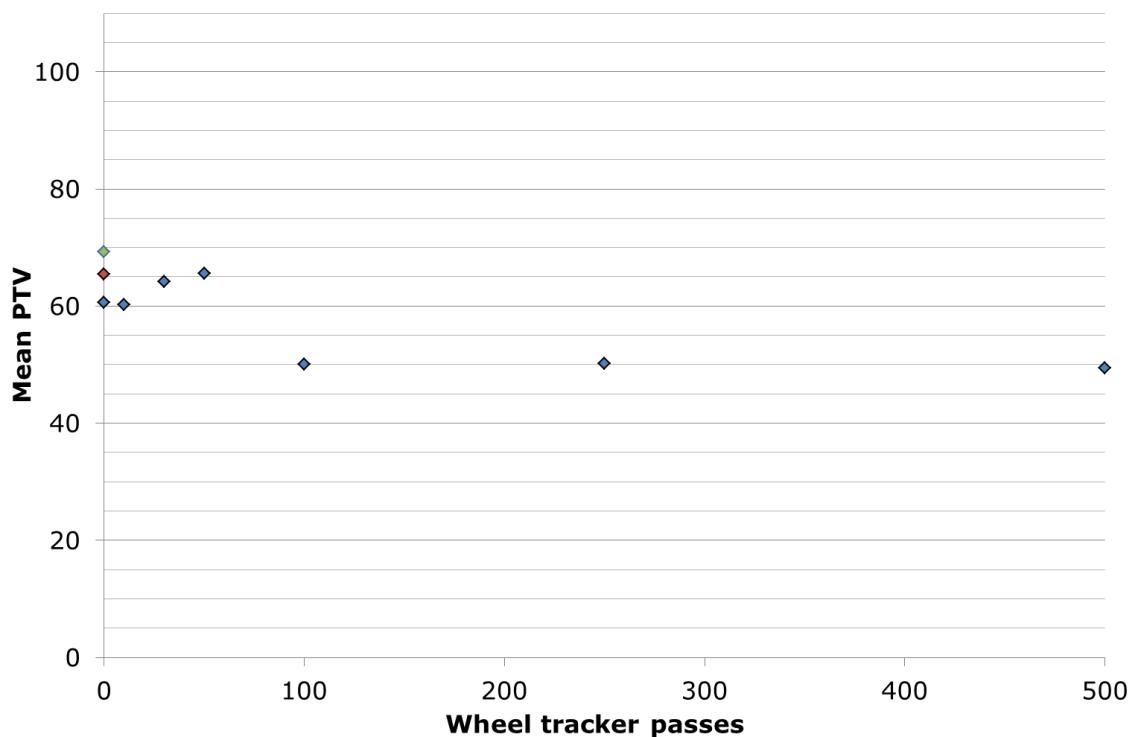
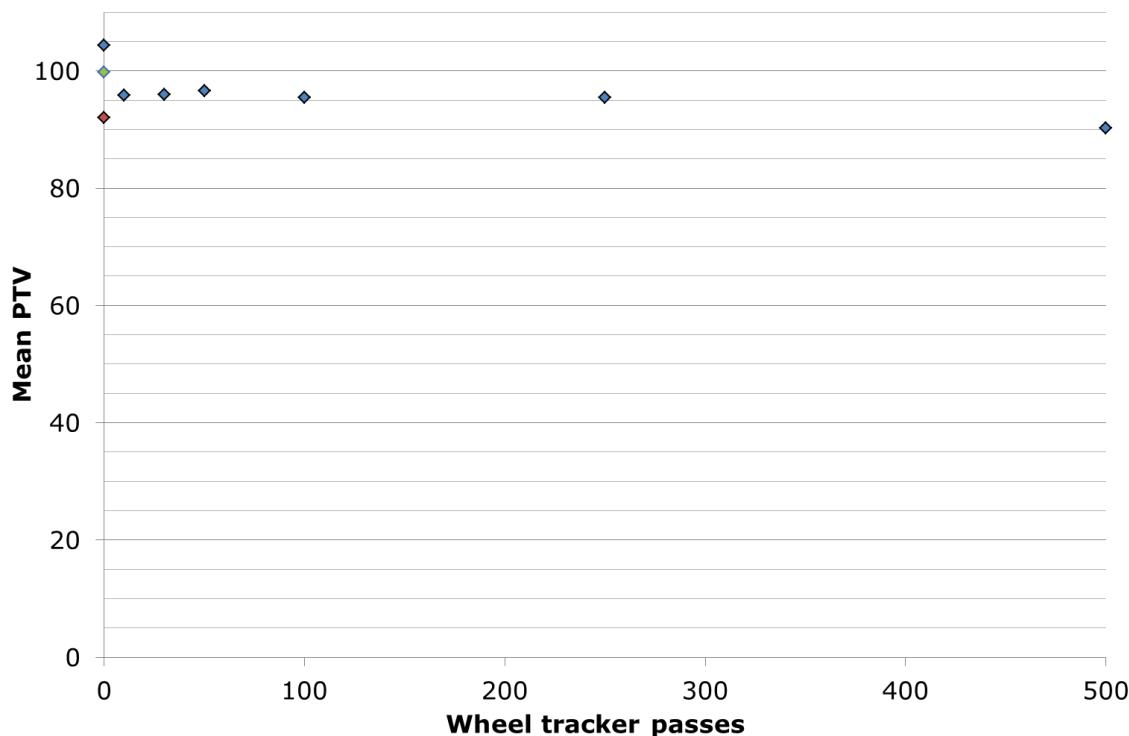
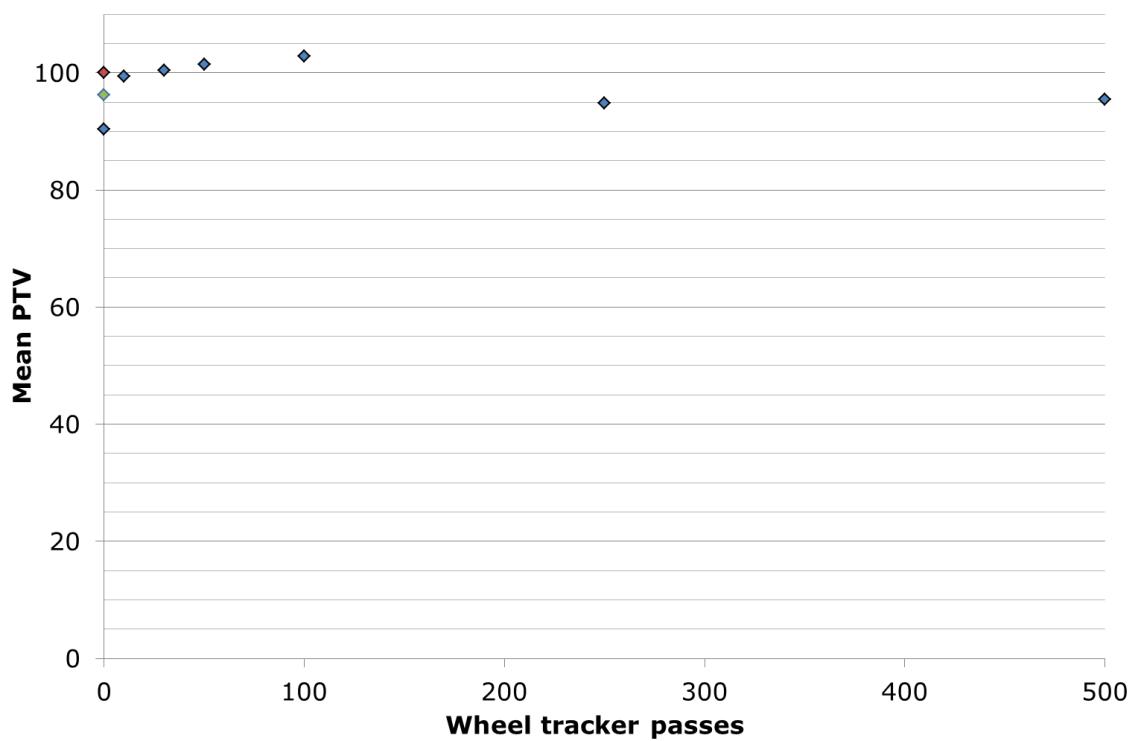
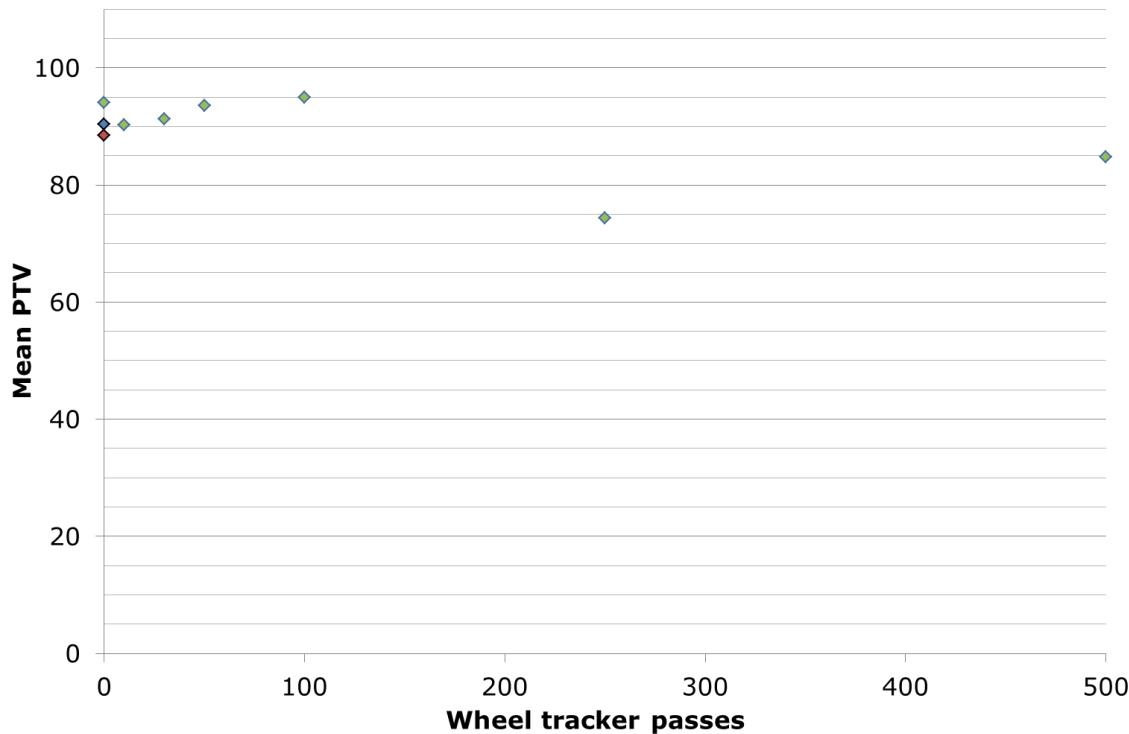


Figure A - 15 Lego

A.2.5 Resin bonded materials**Figure A - 16 Pea gravel****Figure A - 17 Chinese bauxite 0.9-1.4mm**

**Figure A - 18 Chinese bauxite 1-3mm****Figure A - 19 Guyanan bauxite 0.9-1.4mm**

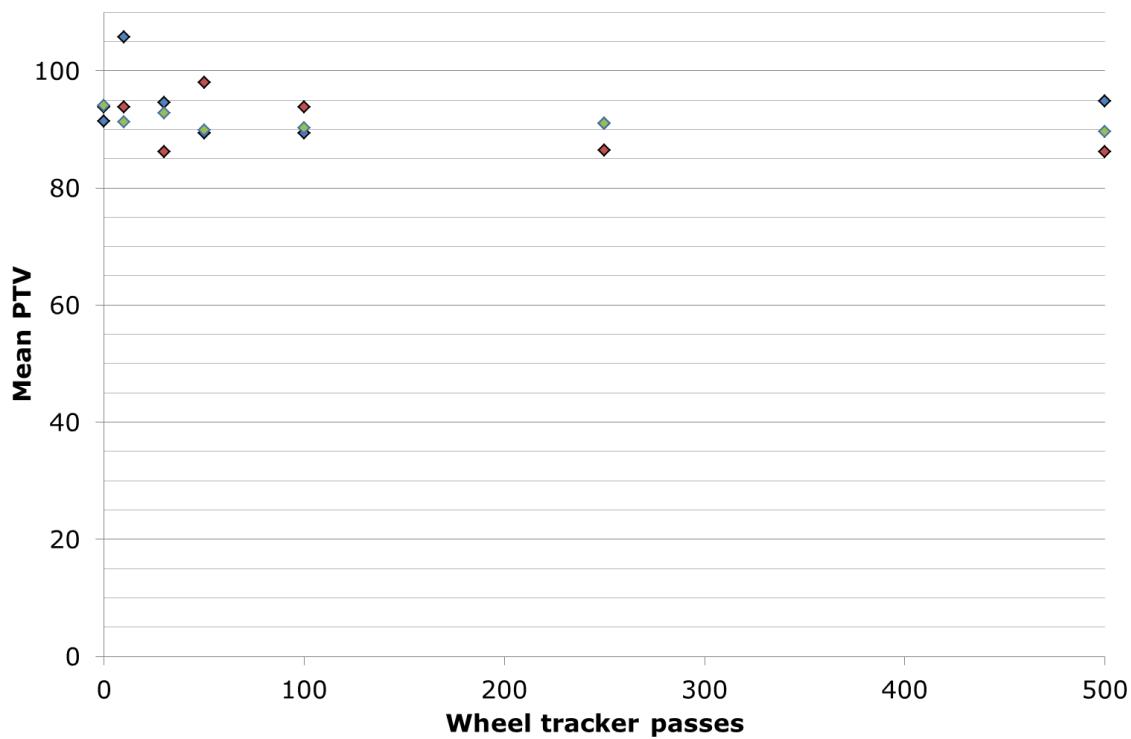


Figure A - 20 Guyanan bauxite 1-3mm

A.2.6 Traditional asphalt road surfacings

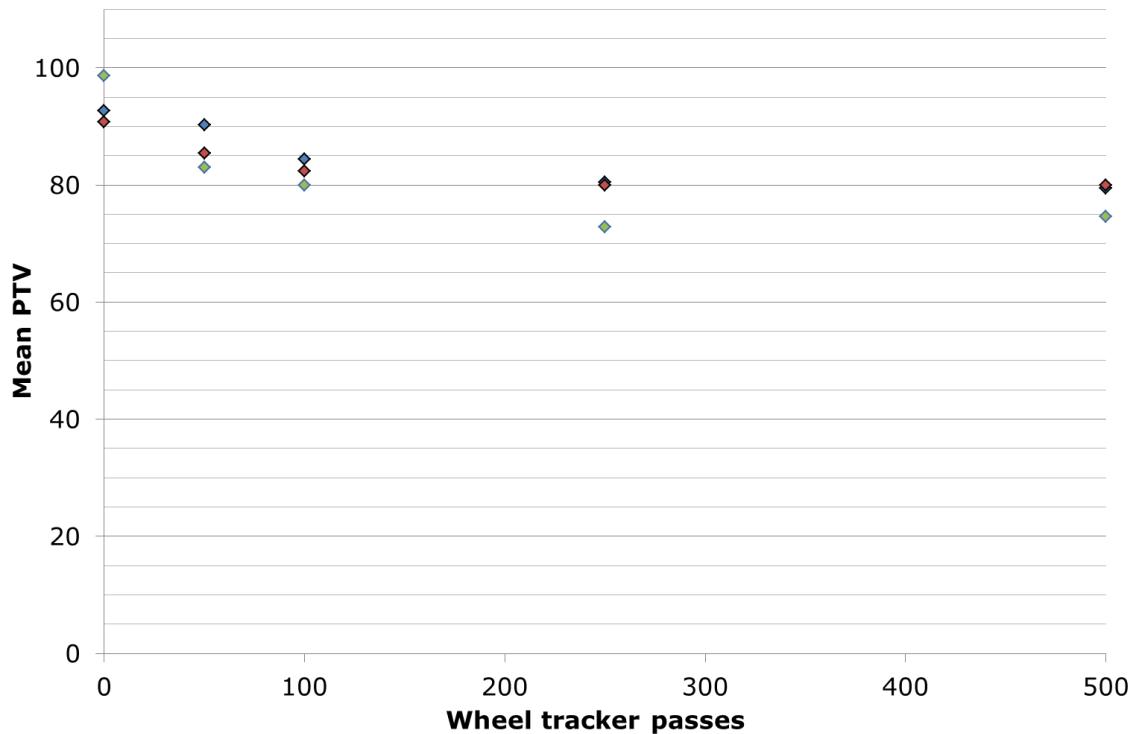


Figure A - 21 10mm TSCS

Appendix B Assessment of surface specimen materials

The following tables summarise the assessment of surface types by answering each of the relevant, "green", questions posed in Figure 4-1. Below is a list of tables provided in this section and the material types that they represent:

Ceramics

- Table B - 1 Anthracite ceramic floor tile
- Table B - 2 Non-slip tile
- Table B - 3 Graphite structured tile

Abrasive sheets

- Table B - 5 P400 A10 abrasive paper
- Table B - 6 P400 SiC abrasive paper

Resin bonded materials

- Table B - 11 Pea Gravel
- Table B - 12 Chinese bauxite
- Table B - 13 Guyanan bauxite

Metals

- Table B - 4 Diamond steel plate

Plastics

- Table B - 7 Rolla-Trac plastic temporary flooring
- Table B - 8 Deck Safe Mini-mesh
- Table B - 9 Deck Safe solid panel top
- Table B - 10

Traditional asphalt road surfacings

- Table B - 14 10 mm TSCS
- Figure A - 21 10mm TSCS

B.1 Ceramics

Table B - 1 Anthracite ceramic floor tile

Question	Answer
Is the friction level acceptable?	Yes – the initial PTV was 22.0
Does the material polish or wear with use?	No – The range of all PTV values was 0.60.
Is the material produced consistently?	Yes – The range of initial PTV values between specimens was 1.6
Conclusion	Material may be suitable as a long term or disposable system.

Table B - 2 Non-slip tile

Question	Answer
Is the friction level acceptable?	Yes – the initial PTV was 30.9
Does the material polish or wear with use?	Yes – The range of all PTV values was 5.0 and the 90 th percentile range of values was 4.6.
Is the material produced consistently?	Yes – The range of initial PTV values between specimens was 0.4
Conclusion	Material may be suitable as a disposable system only.

Table B - 3 Graphite structured tile

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 46.0
Does the material polish or wear with use?	Yes – The range of all PTV values was 11.6 and the 90 th percentile range of values was 10.5.
Is the material produced consistently?	No – The range of initial PTV values between specimens was 5.8
Conclusion	Material is unsuitable.

B.2 Metals**Table B - 4 Diamond steel plate**

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 36.0
Does the material polish or wear with use?	Yes – The range of all PTV values was 15.0 and the 90 th percentile range of values was 10.4.
Is the material produced consistently?	No – The range of initial PTV values between specimens was 10.0.
Conclusion	Material is unsuitable.

B.3 Abrasive sheets**Table B - 5 P400 AIO abrasive paper**

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 77.5
Does the material polish or wear with use?	Yes – The range of all PTV values was 28.0 and the 90 th percentile range of values was 15.7.
Is the material produced consistently?	No – The range of initial PTV values between specimens was 11.0.
Conclusion	Material is unsuitable.

Table B - 6 P400 SiC abrasive paper

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 87.5
Does the material polish or wear with use?	Yes – The range of all PTV values was 18.2 and the 90 th percentile range of values was 15.2.
Is the material produced consistently?	Yes – The range of initial PTV values between specimens was 3.6.
Conclusion	Material may be suitable as a disposable system only.
	No.
Could the material provide multiple friction levels?	<p>Further grades of SiC abrasive paper were assessed for initial PTV the results are below:</p> <ul style="list-style-type: none"> • P240 = 85.4 • P600 = 93.8 • P1200 = 89.0 • P2500 = 88.8

B.4 Plastics

Table B - 7 Rolla-Trac plastic temporary flooring

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 50.1
Does the material polish or wear with use?	Yes – The range of all PTV values was 10.0 and the 90 th percentile range of values was 9.1.
Is the material produced consistently?	This was not assessed
Conclusion	Material is unsuitable.

Table B - 8 Deck Safe Mini-mesh

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 83.3
Does the material polish or wear with use?	Yes, but further investigation could be useful – The range of all PTV values was 5.2 and the 90 th percentile range of values was 4.4.
Is the material produced consistently?	Yes – The range of initial PTV values between specimens was 4.2
Conclusion	Material may be suitable as a long term or disposable system.

Table B - 9 Deck Safe solid panel top

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 66.7
Does the material polish or wear with use?	Yes - The range of all PTV values was 18.6 and the 90 th percentile range of values was 12.7.
Is the material produced consistently?	No – The range of initial PTV values between specimens was 6.2
Conclusion	Material is unsuitable.

Table B - 10 Lego

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 35.1
Does the material polish or wear with use?	No - The range of all PTV values was 4.4 and the 90 th percentile range of values was 3.0.
Is the material produced consistently?	Yes – The range of initial PTV values between specimens was 1.2
Conclusion	Material may be suitable as a long term or disposable system.

B.5 Resin bonded materials

Table B - 11 Pea Gravel

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 59.4
Does the material polish or wear with use?	Yes - The range of all PTV values was 19.8 and the 90 th percentile range of values was 18.1.
Is the material produced consistently?	No – The range of initial PTV values between specimens was 8.6
Conclusion	Material is unsuitable

Table B - 12 Chinese bauxite

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 96.18
Does the material polish or wear with use?	Yes - The range of all PTV values was 14.2 and the 90 th percentile range of values was 11.6.
Is the material produced consistently?	No – The range of initial PTV values between specimens was 12.4
Conclusion	Material is unsuitable

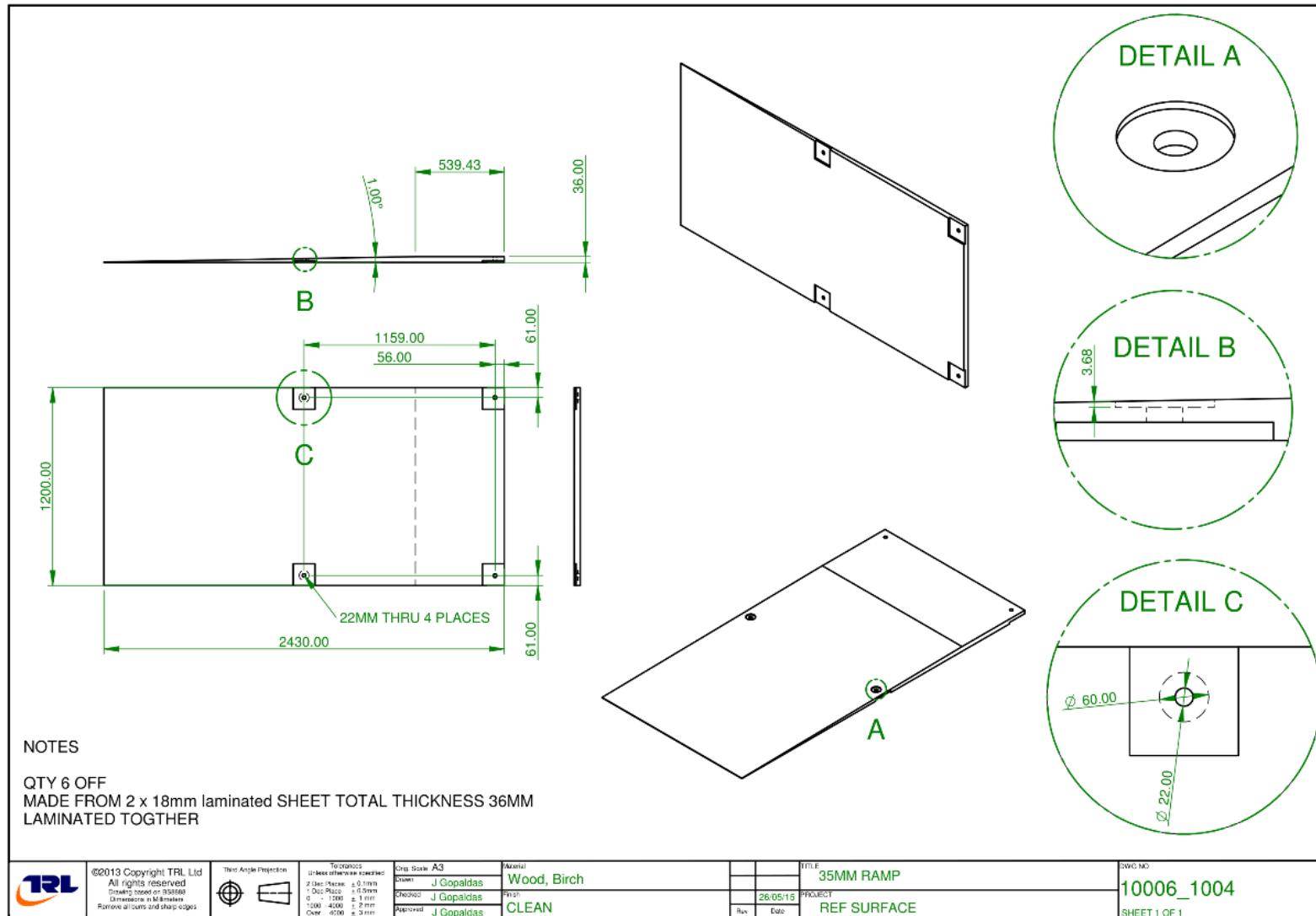
Table B - 13 Guyanan bauxite

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 89.11
Does the material polish or wear with use?	Yes - The range of all PTV values was 20.6 and the 90 th percentile range of values was 16.0.
Is the material produced consistently?	No – The range of initial PTV values between specimens was 5.6
Conclusion	Material is unsuitable

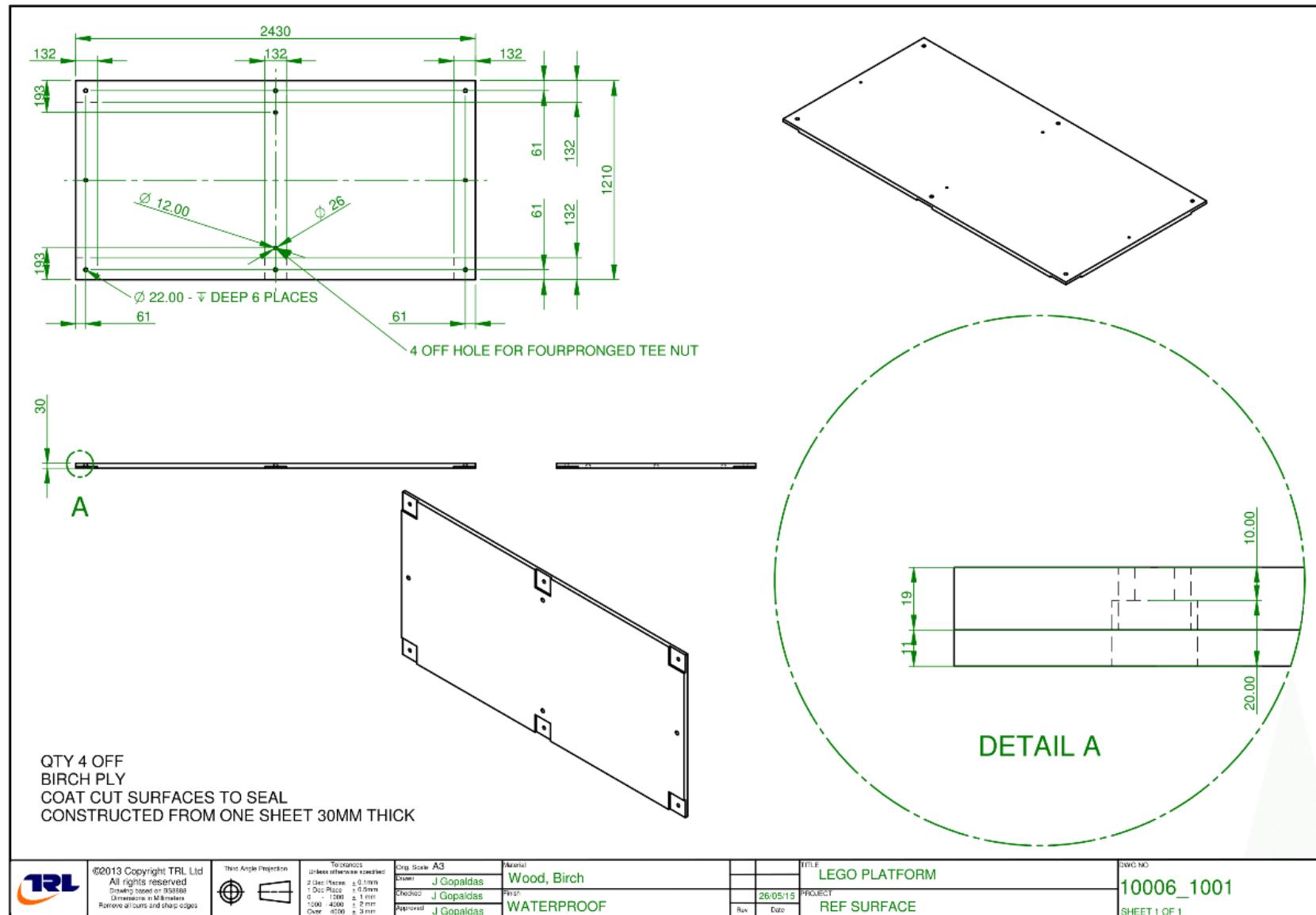
Table B - 14 10 mm TSCS

Question	Answer
Is the friction level acceptable?	Yes – average PTV was 83.9
Does the material polish or wear with use?	Yes - The range of all PTV values was 25.8 and the 90 th percentile range of values was 20.3.
Is the material produced consistently?	No – The range of initial PTV values between specimens was 7.8
Conclusion	Material is unsuitable

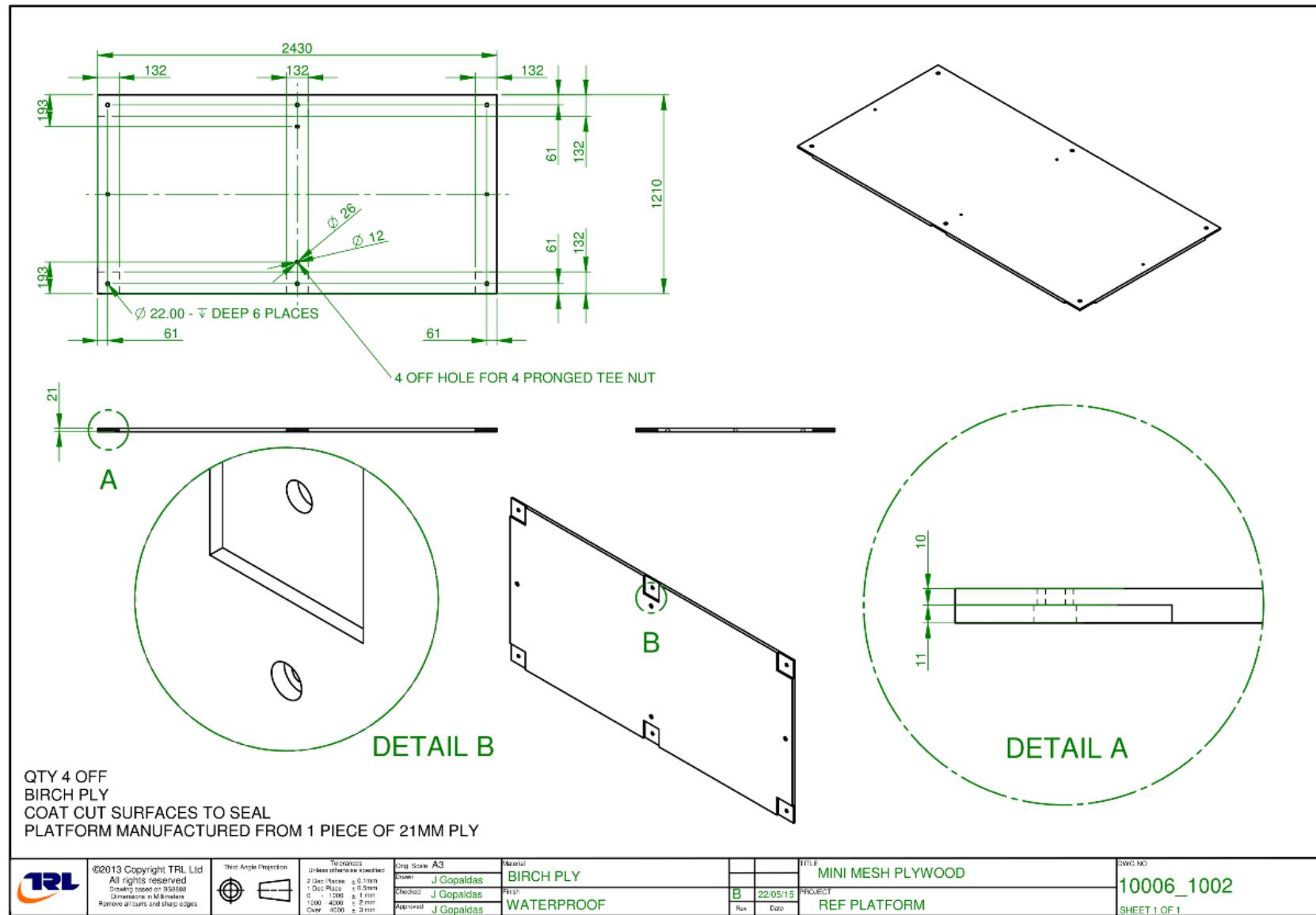
Appendix C Surface prototype technical drawings



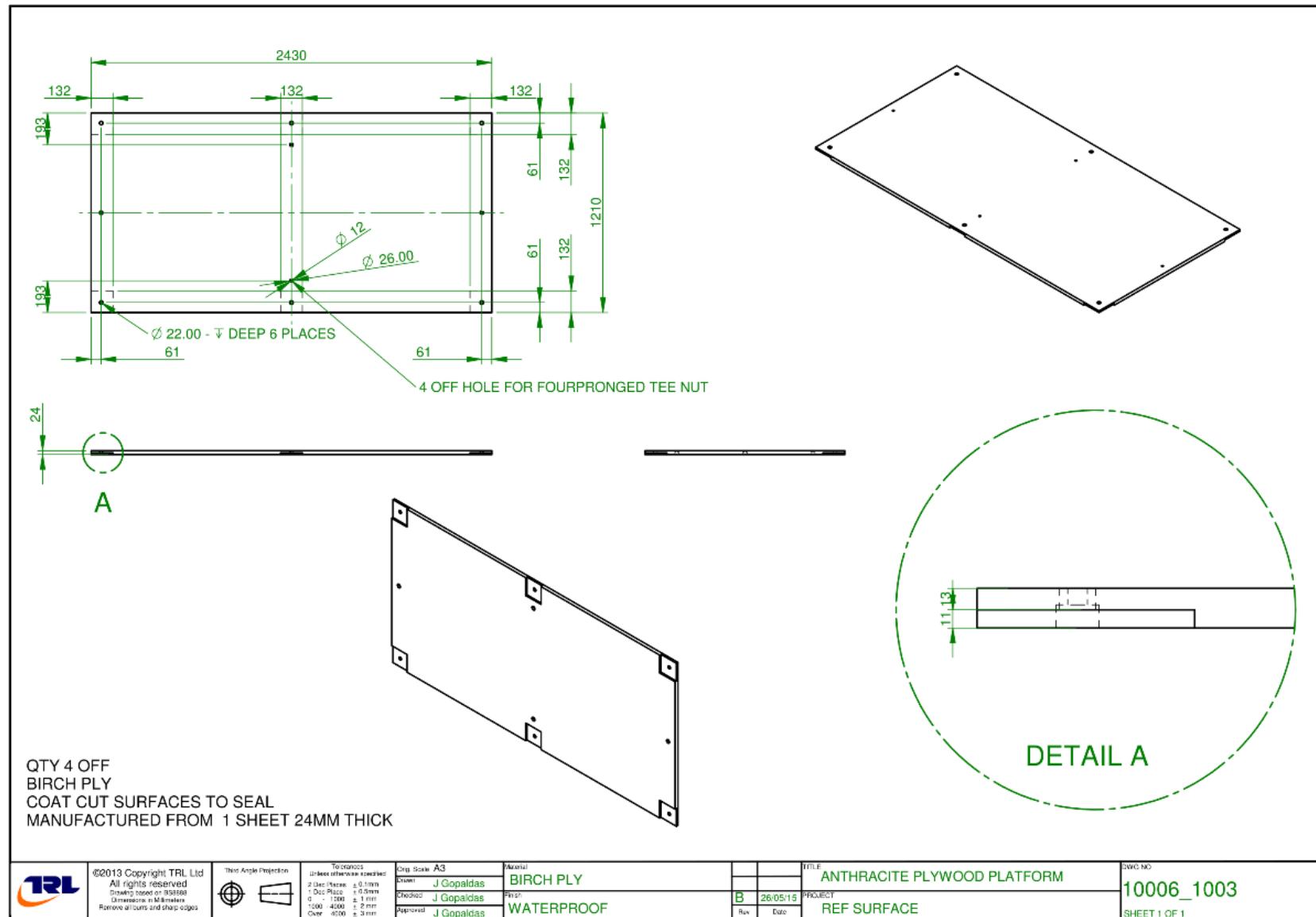
Appendix C - 1 Ramps



Appendix C - 2 Lego section



Appendix C - 3 Mini-mesh section



Appendix C - 4 Anthracite tile section

Appendix D Characterisation of candidate surfaces

D.1 Control

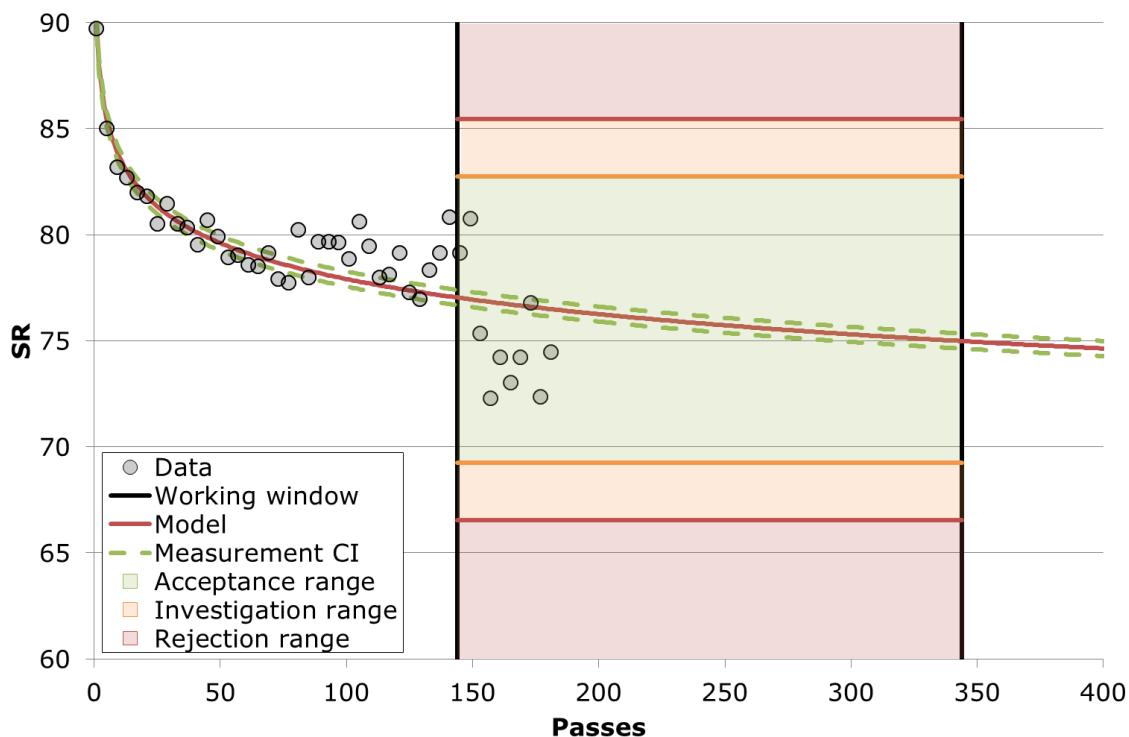


Figure D - 1 Characterisation of static machine acceptance criterion

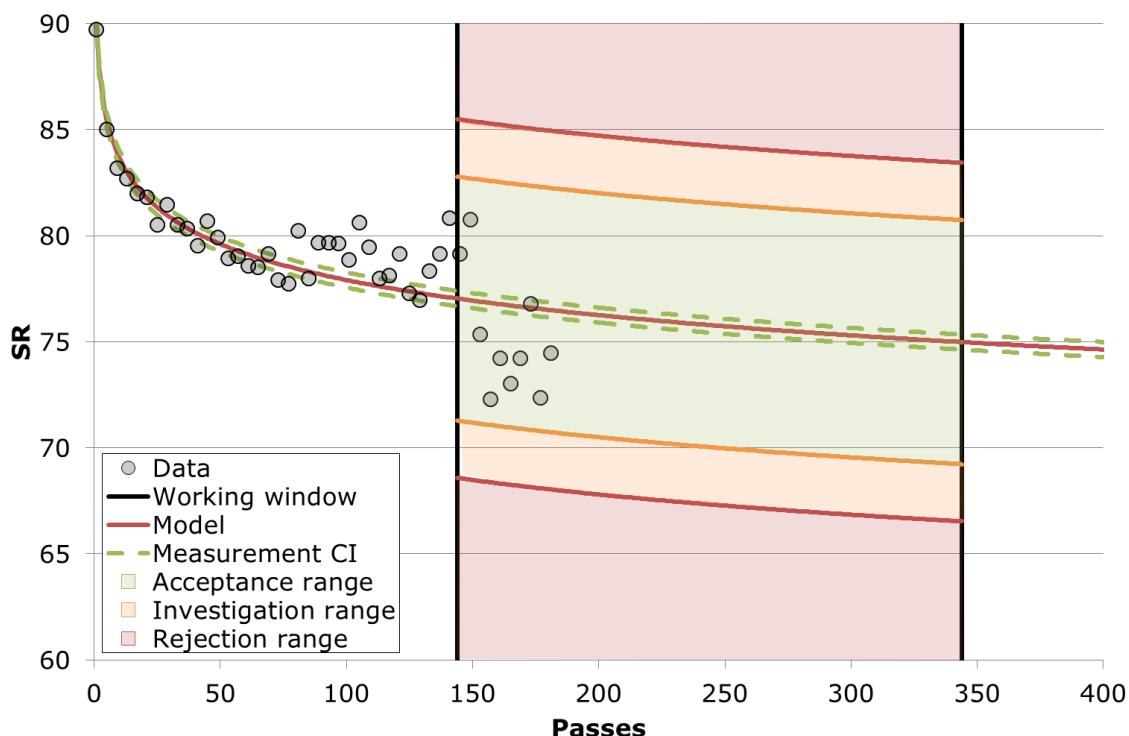


Figure D - 2 Characterisation of dynamic machine acceptance criteria

D.2 Lego

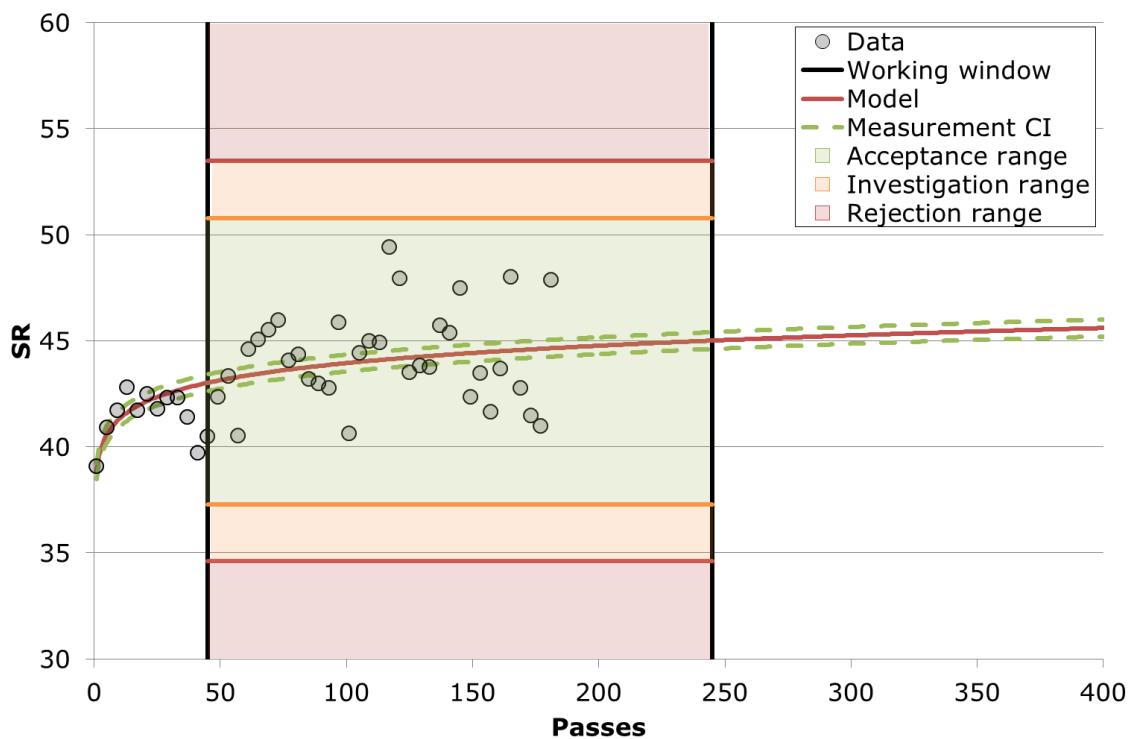


Figure D - 3 Characterisation of static machine acceptance criterion

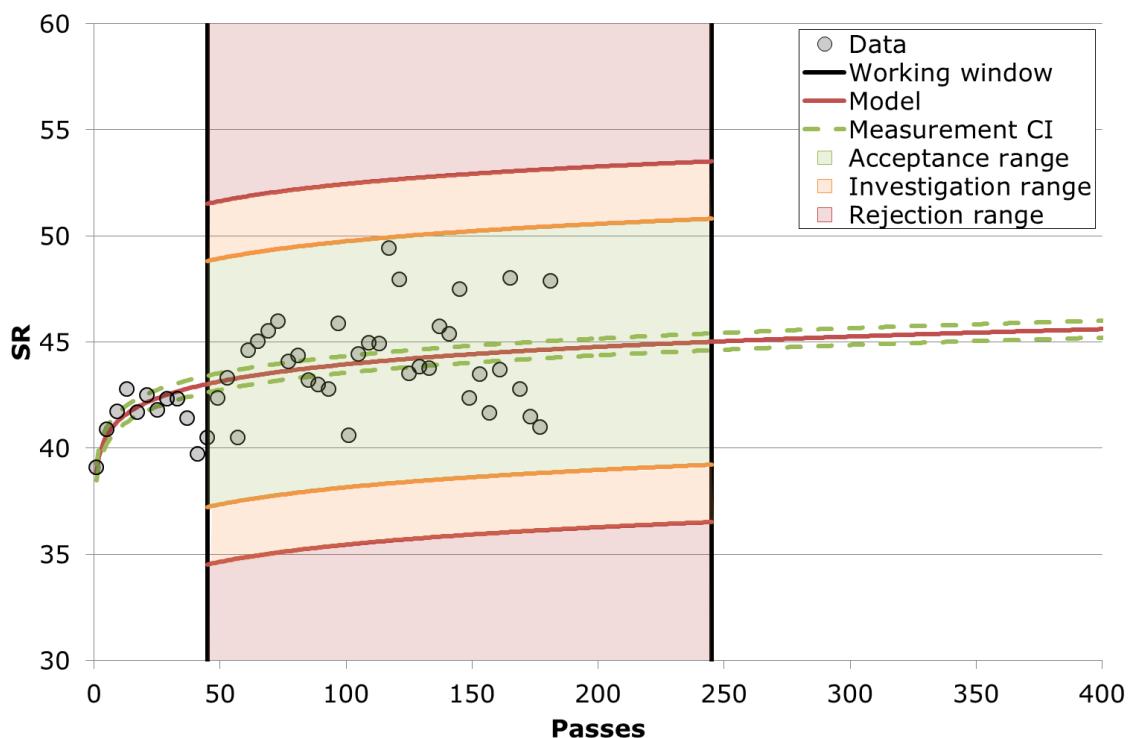
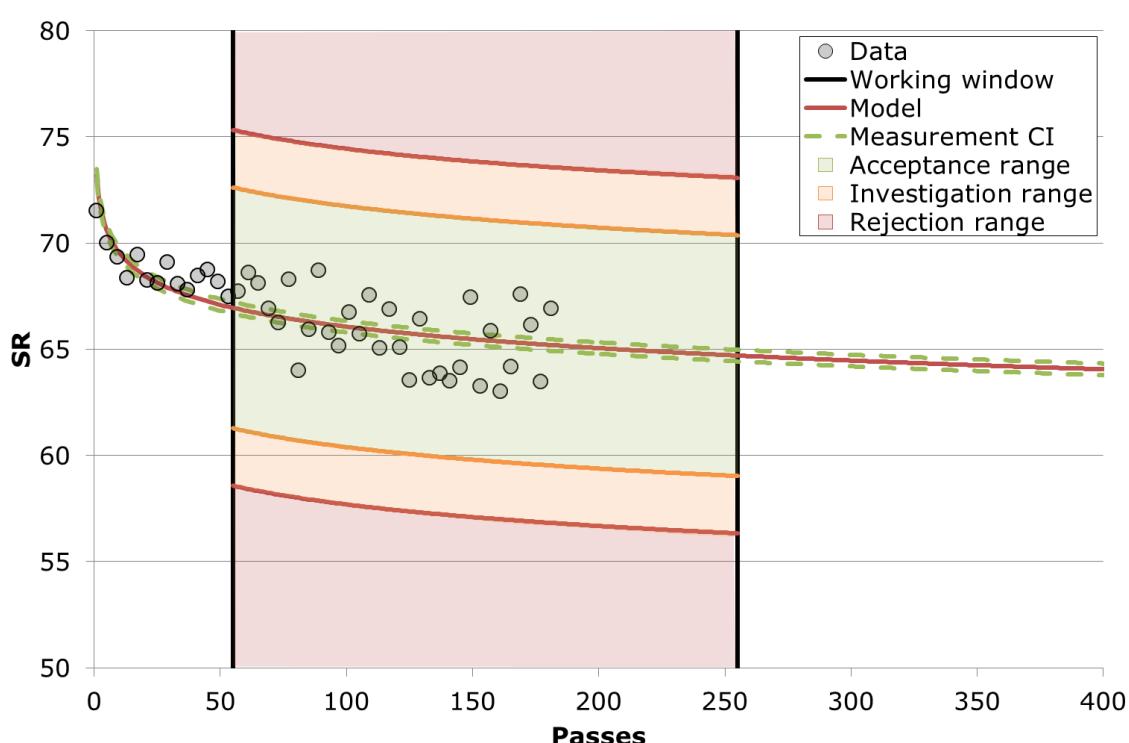
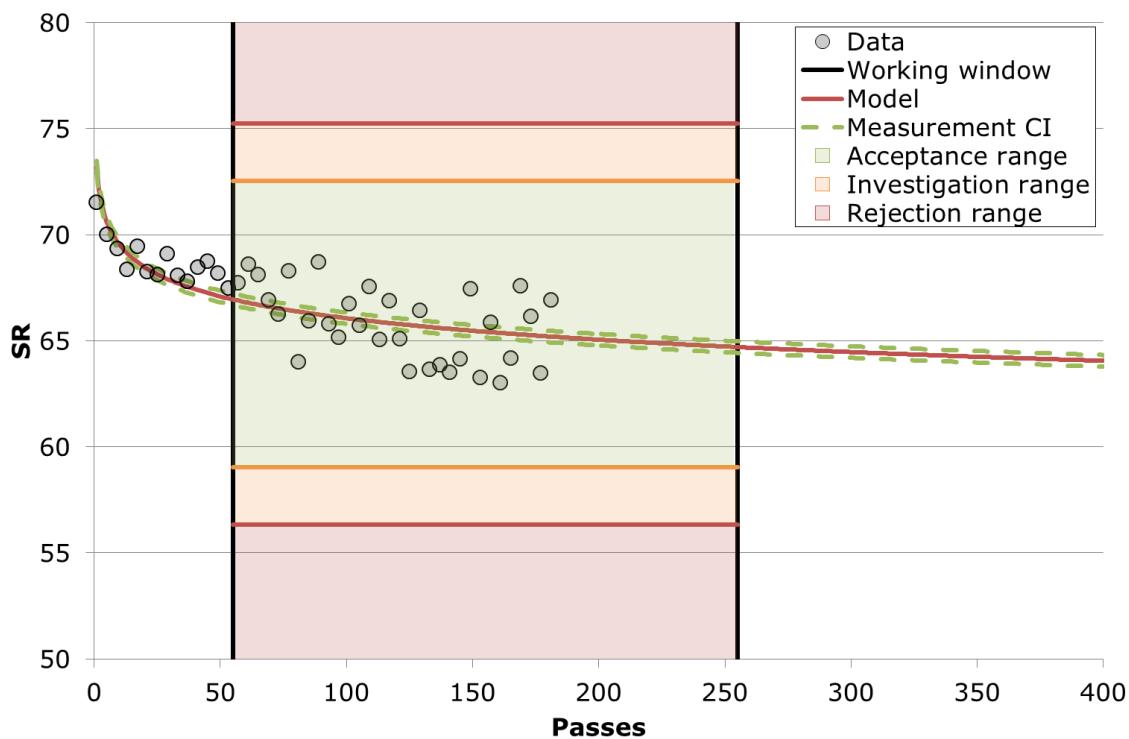


Figure D - 4 Characterisation of dynamic machine acceptance criteria

D.3 Mini-mesh



D.4 Anthracite tile

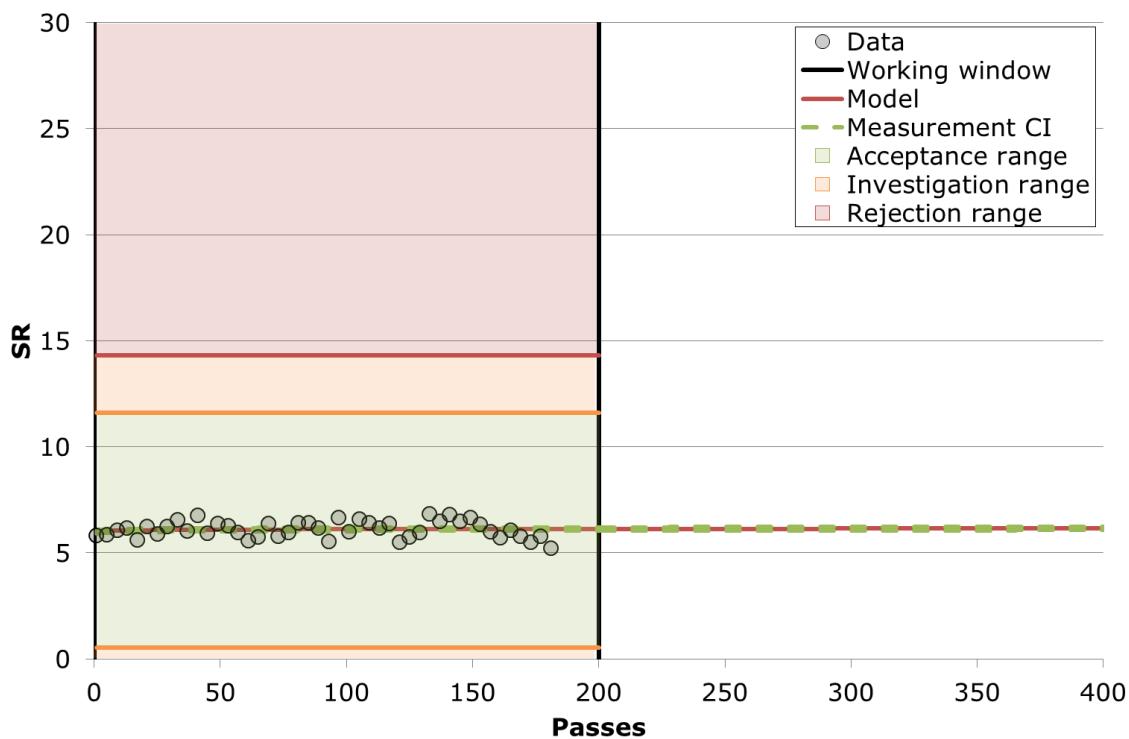


Figure D - 7 Characterisation of static machine acceptance criterion

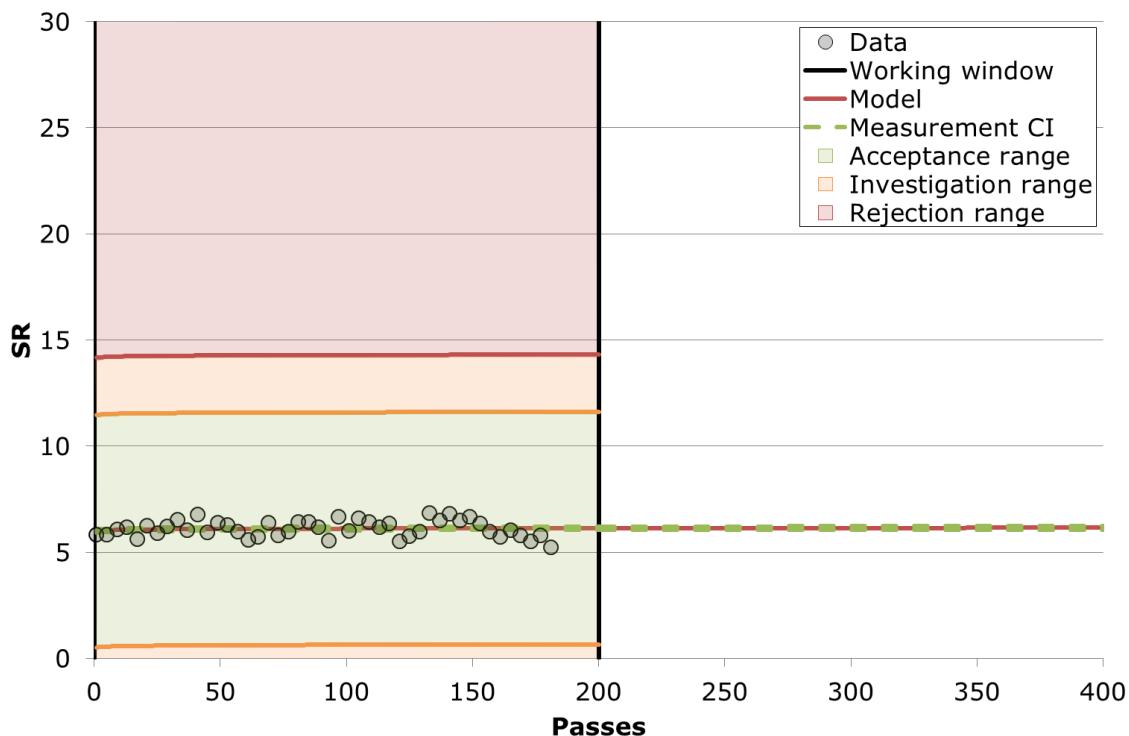


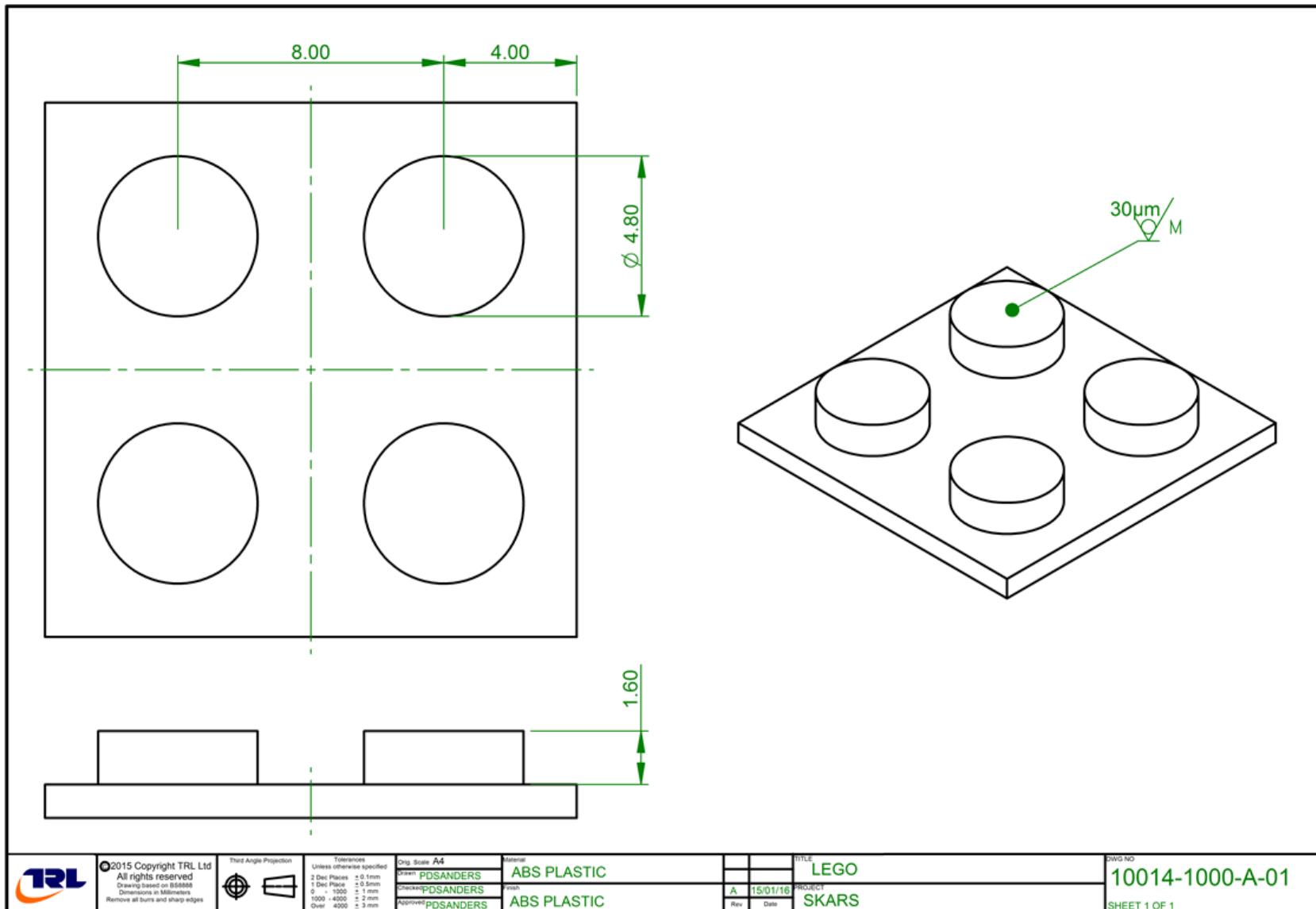
Figure D - 8 Characterisation of dynamic machine acceptance criteria

Appendix E Description of reference surface materials

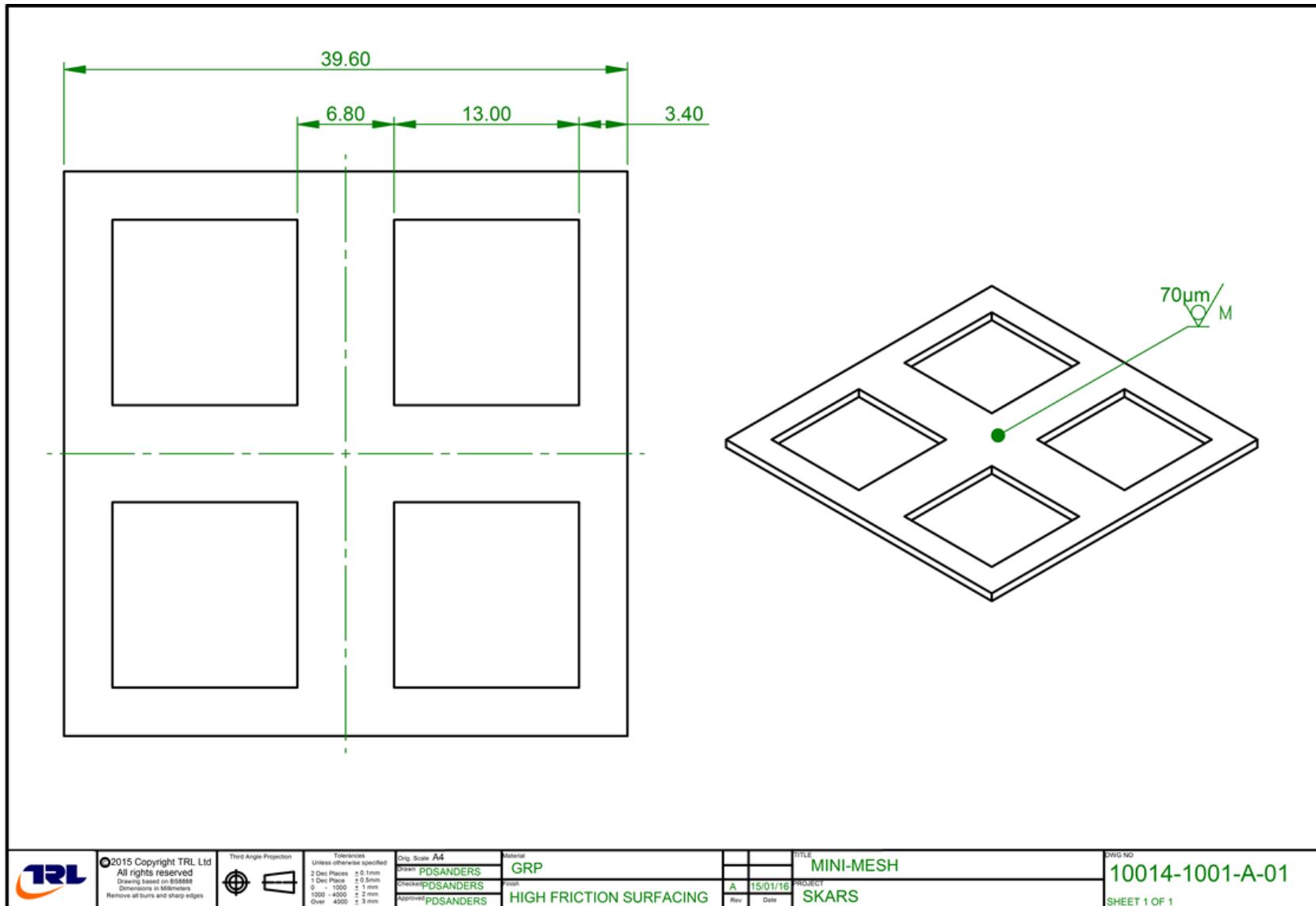
The following technical drawings provide the key characteristics of the materials used in the full scale testing phase. Given that the materials used are proprietary products, it is not possible to provide their full specification.

For this application, the salient information is the surface characteristics, namely the geometry and roughness values. The surface geometry for each material was measured directly from the surfaces used in the full scale testing. The roughness values (reported as values of Ra (as defined by (British Standards Institution, 2000) and represented by the \checkmark^M symbol) were estimated from three dimensional computer models of the surface microtexture. Models of the Mini-mesh and tile surfaces were made using the Breuckmann SmartScan 3D camera system. A model of the Lego surface was made using manual measurements. These models were then interrogated using the Mountains Map Universal software which was used to calculate the Ra roughness values.

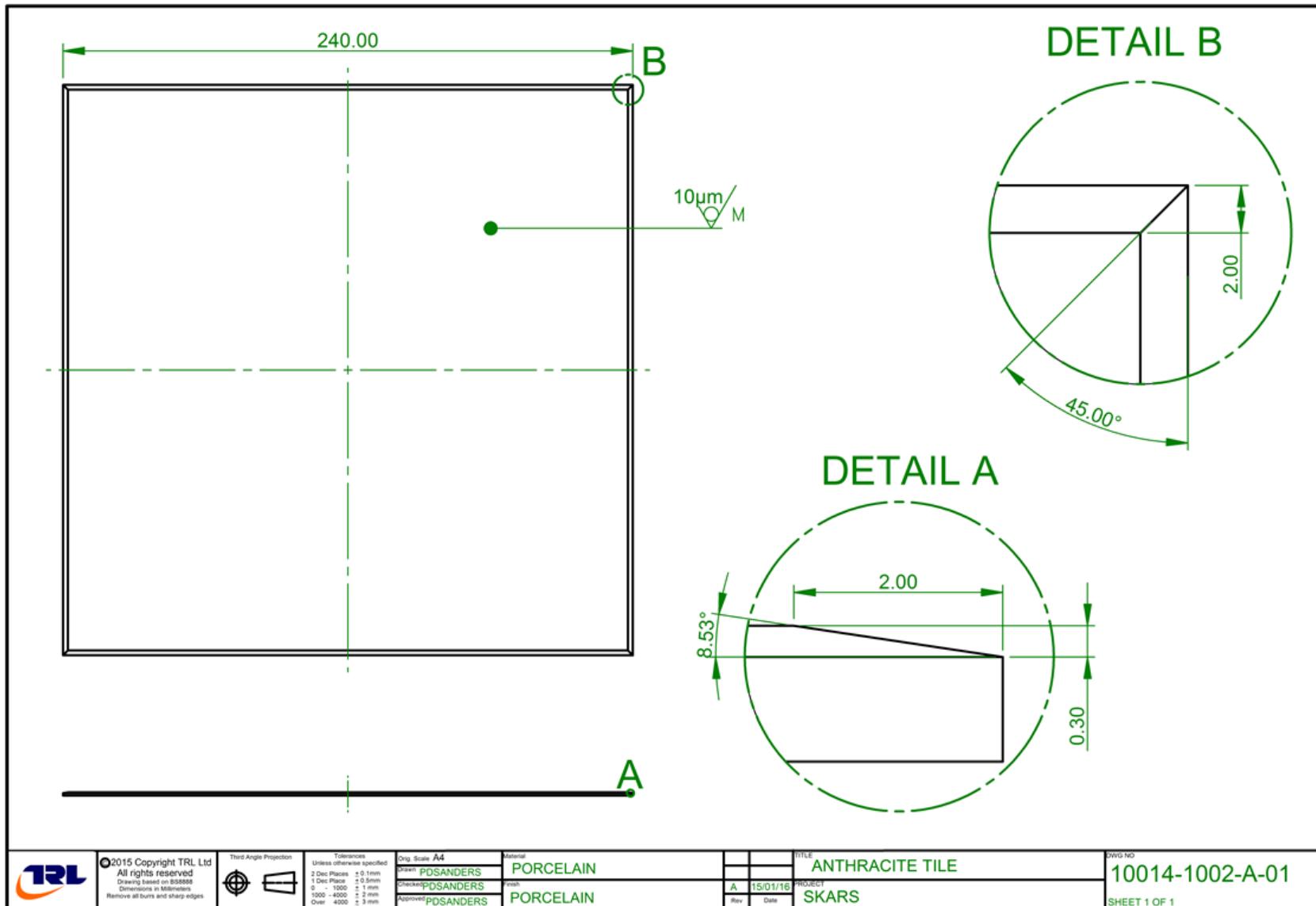
The following drawings show small sections of the surfacings used in the full scale testing. For practical application, these should be tessellated to provide full scale surfacings of the required dimensions.



Appendix E - 1 Lego



Appendix E - 2 Mini-mesh



Appendix E - 3 Anthracite tile