INSTITUTE FOR FRONTIER MATERIALS
deakin.edu.au/ifm

Road Surface Testing

On-road impact abrasion testing on Victorian asphalt and chip seal roads.

June 2022.

This report was prepared by Christopher Hurren, Zahra Komeily Nia, Bijan Nasri-Nasrabadi, Rodney Taylor and Liz de Rome from the Institute for Frontier Materials, Deakin University, Geelong, Victoria.

The project was funded by the Motorcycle Safety Levy, Department of Transport, Road Safety Victoria.

The authors would like to acknowledge and thank Russell Higgins, Senior Project and Policy Officer – Safer Vehicles and Future Vehicle Technology, Department of Transport, Road Safety Victoria for his input and comments.

For further information please contact:

Christopher Hurren PhD

Senior Research Fellow – Fibre Science and Technology
Institute for Frontier Materials, GTP Research

Deakin University
Geelong Waurn Ponds Campus, Locked Bag 20000, Geelong, VIC 3220
christopher.hurren@deakin.edu.au

+61 3 5227 2374

Contents

Executive summary

This report describes the results and findings of the road surface testing trial conducted on Victorian Roads during the first six months of 2021.

The aim of this work was to assess the abrasion damage done to motorcycle protective clothing on a number of road surfaces in Victoria, Australia. This information will help to determine if there is clothing that is more suited to Victorian roads and if there are road surfaces more likely to damage motorcycle clothing during a crash. This information will also be used to advise on the suitability of the Cambridge impact abrasion tester for reporting on MotoCAP. A car mounted Cambridge type impact abrasion tester was used to assess road surfaces. Testing was conducted using six common motorcycle clothing material combinations. All of the test samples were measured on a Mesdan laboratory Cambridge impact abrasion tester to provide a benchmark for their performance.

The roads selected were asphalt, single aggregate chip seal, dual aggregate chip seal, mixed aggregate and geotextile reinforced dual aggregate chip seal. Asphalt has a smoother surface than chip seal and was selected as it is predominately found in an urban environment or on high use roads such as motorways. Single aggregate chip seals were selected as they are common on rural A, B and C roads. As mean aggregate sizes of 10 and 14mm are the most commonly used on roads these were selected to determine if aggregate size influences abrasion time.

Dual aggregate chip seals are more common on high use roads such as A roads and motorways. The roads are made by first laying the larger aggregate before over laying with the smaller aggregate. Two surfaces were trialled where the larger aggregate was varied in size (14mm and 20mm) and the smaller aggregate was fixed at 7mm. These are named as 14/7 and 20/7 in this report. 14/7 is more commonly used than 20/7 in Victoria.

Two new surfaces were also included in testing. One was a mixed aggregate road that saw a 7mm surface covered by a 20mm aggregate and then a further 7mm aggregate. This surface was being trialled in Victoria for durability and was included to determine its performance in comparison to dual aggregate surfaces. It has been referred to as 20/7/7 in this report. The other was a geotextile reinforced 14/7 surface. This surface was laid as a 10mm single aggregate base then covered by a geotextile and then covered again by a 14/7 dual aggregate surface as described in the previous paragraph. This surface was also a trial surface for use in locations that require higher durability of the surface. It had the added advantage of providing a very flat road surface.

Preliminary findings of this work are:

- Asphalt surfaces take on average four and a half times longer to hole clothing than the laboratory Cambridge impact abrasion test machine and chip seal surfaces.
- Protective denim and leather fabrics displayed the highest abrasion time among all the protective textiles on all road surfaces.
- On most road surfaces the protective denim fabric combination performed the best of all material types tested.
- The laboratory Cambridge impact abrasion test machine gave similar results as to most single and dual aggregate chip seal surfaces and is highly suitable for advising protection levels to Australian and New Zealand riders.
- The laboratory Cambridge impact abrasion test machine with a 60-grit belt is suitable for MotoCAP testing.
- Aggregate size had little influence on the abrasion time to hole for single aggregate surfaces.
- Aggregate shape and macrostructure had a large influence on abrasion time to hole.
- Cubical shaped aggregate used in a chip seal surface was more likely to damage motorcycle clothing than a surface made from the equivalent size flat aggregate.
- Dual aggregate surfaces were more likely to damage motorcycle clothing if there was a large differential between the two aggregate sizes.
- The 20/7mm 20/7/7mm multi aggregate surfaces were highly abrasive to motorcycle clothing and should only be used for high motorcycle use roads when all other alternatives are unsuitable.
- Thermal damage to samples may be possible on asphalt surfaces however more testing is required to fully understand the area.
- The results of this work reinforce the message that two star or better clothing is suitable for an urban environment and three star or better clothing is recommended for rural riding.

1 Introduction

Motorcyclists are a vulnerable road user group who represent an increasing proportion of road crash casualties. The use of protective clothing to reduce injury to motorcyclists has been the subject of scientific discussion for many years(CEN, 2002b; Cortili, Mognoni, & Saibene, 1996; Nunneley, 1989; Schuller, Beir, & Spann, 1986; Zettas, Zettas, & Thanasophon, 1979). Research studies have confirmed the value of protective clothing in reducing the frequency and extent of abrasions and lacerations and subsequent disability in motorcycle crashes(L de Rome et al., 2011; L. de Rome et al., 2012). While there is evidence that specialised motorcycle protective clothing may significantly reduce the risk and severity of injuries in crashes, there is also evidence that over 25% of the protective clothing worn by motorcyclists in Australia is of inferior quality and may fail under crash conditions(Albanese et al., 2017; L de Rome, 2018; L de Rome et al., 2011).

Motorcycle clothing is made from a range of materials. Traditionally clothing was made from top grain or full grain leather. In the last forty years textile garment materials have transformed. By utilising thicker fabrics and higher strength polymer fibres manufacturers expanded their use from just providing protection from the weather to injury protection as well. The most common of these are woven fabric made from continuous filament nylon and polyester. 30 years ago, the clothing market changed again with the addition of denim jeans lined with protective fabrics made from para-aramid (Kevlar, Twaron), ultra-high molecular weight polyethylene (Dyneema, Spectra, UHMWPE) and aromatic polyester liquid crystal (Vectran) polymers. The casualisation of protective clothing has seen a range of casual clothing with incorporated protective elements. There is limited information on the way that clothing interacts with Australian roads.

The four main road surface types include asphalt, chip seal, slurry seal and concrete. Road surface is selected on a variety of parameters including cost, durability, road use, aggregate availability and grip required due to prevailing weather conditions (Austroads, 2000; NZ, RCA, & NZ, 2005). Road parameters believed to affect abrasion of motorcyclist clothing in a crash are size and type of aggregate, laying method and road surface macro-texture. Macro-texture can vary from 0.5 to 10mm and determines the number of surface elements that interact with a crashed riders clothing during abrasion. Australian roads are predominately made up of chip seal and asphalt with a limited amount of concrete. There is no known work evaluating the effect of different road surface on the abrasion of motorcycle clothing.

There are three different test methods for the evaluation of impact abrasion of clothing and gloves employing two different impact abrasion test machines. EN13595-2:2002 utilises the Cambridge type impact abrasion tester using a 60 grit test belt (CEN, 2002a). EN13594:2015 follows the same abrasion method as EN13595-2:2002 but utilises a finer abrasive size 120 grit test belt (CEN, 2015). EN17092-1:2020 has adopted the Darmstadt Advanced Abrasion Resistance Tester (AART) (Darmstadt, 2018) using a concrete test pad (CEN, 2020). The rationale for changing from the 60 to 120 grit belt on the Cambridge machine for measuring gloves was due to an anecdotal report that the 60 grit belt gave low repeatability of measurement for lower performing protective materials. The Darmstadt machine was incorporated in the new European standard as manufacturers felt that it better simulated typical European roads than the Cambridge machine.

The Cambridge type impact abrasion tester was developed by Dr Roderick Woods based on damage present in clothing recovered from emergency department presentations (Woods, 1996a, 1996b, 1996c). These were augmented with controlled testing of a fully clothed mannequin in high-speed road testing. Many parameters were evaluated including belt speed, impact height, belt grit, test arm mass and sample test area. It was settled that an OP60 grit belt traveling at 8m/s would abrade a 1963mm^2 test area that was dropped from 50mm high with a weight of 5kg. These settings provided the best repeatability and replication of impact abrasion failure from the captured road damaged garments. There have been several subsequent research articles that support the work of Dr Woods (L de Rome, Meredith, Ivers, & Brown, 2014; Meredith et al., 2016; Meredith et al., 2017). These included a comparison of the impact abrasion resistance of a material with the soft tissue injuries of riders attending an emergency department. This method was selected as the one used by MotoCAP due to the level of analysis and verification against accident damage that has so far been conducted.

The aim of this work was to assess the abrasion damage done to motorcycle protective clothing on a number of road surfaces in Victoria, Australia. This information will help to determine if there is clothing that is more suited to Victorian roads and if there are road surfaces less suited to motorcycle crashes. This information will also be used to advise on the suitability of the Cambridge impact abrasion tester for reporting on MotoCAP.

2 Methodology

2.1 Test fabrics

The test fabrics were selected in order to cover the widest range of garment types used by riders. Protective textiles form the largest class of garments being worn by road riders. Protective textiles are commonly made of nylon and polyester. The body of most protective textile garments are made from a lighter weight fabric (400-600 denier). Some garments will contain reinforcement layers in the higher abrasion risk areas (1000-1800 denier). Three protective textile fabrics were selected to represent each of these different materials.

Leather still plays a dominant role in motorcycle protective garments with leather jackets commonly worn by riders. Most garments are constructed from a dyed full grain or top grain leather. The tighter surface grain structure of full grain leather makes it preferable for motorcycle clothing applications. Thickness of the leather is also a variable in protection levels. 1.3mm thick, full-grain cows hides were used for all test samples to ensure similarity in the leather test performance.

Protective denim jeans have emerged as a dominant player in the protective clothing space. The higher performing protective denim jeans are made of at least two layers where the outer layer is a traditional cotton denim fabric and the inner protective layer is a knitted fabric made from a high tenacity fibre. The protective layer is typically made from a range of fibres including polyester, para-aramids, ultra-high molecular weight polyethylene and aromatic polyester liquid crystal polymers. Fabrics range from light weight single jersey to heavy weight loop knitted fabrics. In this work a medium weight denim fabric with a knitted double jersey para-aramid liner was used to represent a middle of the range of this class.

The Cambridge impact abrasion tester is calibrated with a cotton canvas standard fabric to assess its level of wear. This two-layer combination has been measured a significant number of times worldwide and it is known to last two seconds on a new belt. The uniformity in the weave structure, the twin layer system of use and the repeatability in the standard manufacture of this product make it a good, repeatable sample to use in these evaluations. Using it on the road surface helps to understand the aggressiveness of that surface compared with the Cambridge impact abrasion test machine.

Details of each of the test materials are given below.

- Two layers of the cotton canvas standard calibration fabric
- One layer of cow hide leather and one layer of mesh liner fabric
- One layer of 600 denier polyester and one layer of mesh liner fabric
- One layer of 500 denier nylon and one layer of mesh liner fabric
- One layer of 1600 denier polyester and one layer of mesh liner fabric
- One layer of denim, one layer of Kevlar and one layer of mesh liner fabric

2.2 Laboratory testing

Laboratory testing was conducted on a Mesdan LAB Cambridge type impact abrasion tester using a 60-grit belt. The abrasion testing was conducted following EN13595-2:2002, where six tests were conducted on each material combination. The six tests were split into three groups and tested with two in the zero direction, two at 45° to the belt and two at 90° to the belt. These results were corrected against the calibration tests ran during testing. For textile fabrics the zero direction was when the warp of the fabric was parallel with the belt. For leather the zero direction of the test sample was determined when the hide was laid out flat on a table. The zero test direction was parallel with the line between the head and the tail of the hide.

A further set of five tests for each fabric type was run in the zero orientation to collect the raw values in the same manner as the on-road tests were carried out. The calibration fabric tests were interspersed within the other test samples to ensure that the belt remained within tolerance.

2.3 On-road test rig

The car mounted test rig (Figure 1) was built following the same design criteria as that of a laboratory Cambridge impact abrasion tester. A twin faller arm design was used to ensure that the material samples had a flat contact with the road surface at all heights as suspension travel in the car could not be controlled. The unit was set at approximately a 50mm drop height when it was fitted to the car. The weight was removable and was fixed in a set place to achieve the 5kg test head weight required for testing. The test time was started on release of the test head and stopped on breaking of a fine copper wire on the inside of the test sample. Test control and timing display was undertaken using a cabin mounted LCD screen and control panel operated by the passenger of the car. The test speed of the majority of samples was done using the vehicle’s digital speedo. An indicated test speed of 30km/hr was maintained by the driver for the duration of the test. 30km/hr was used as it was an easier speed to maintain and also to allow for the reading error of the car speedo. The actual test speed once the speedo error was taken into account was 28km/hr. The error that could be introduced by too high or low of test speed due to driver error was 5.5% for 1km/hr either side of the test speed and 11% for 2km/hr either side of the test speed. Testing was done in a zero orientation for all tests as this gave more statistical significance to the results. Some tests were filmed using a GoPro camera mounted on an arm hanging out on the left-hand side of the test frame.

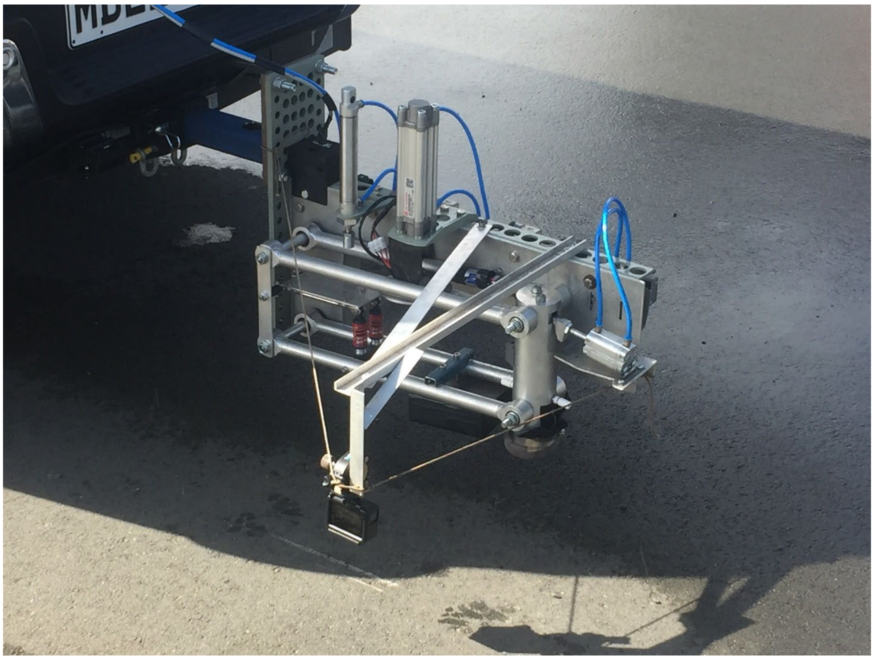


Figure 1. Impact abrasion test rig mounted to a car

2.4 On-road testing

2.4.1 Asphalt

Asphalt is a common surface found in urban areas, motorways and some rural roads. Asphalts are laid by premixing the aggregates with the bitumen and then spreading the heated material to provide an even surface. Asphalts have a negative texture as the holes/surface defects go into the asphalt layer. The surface used in these trials was located at Nicol Drive South on the Deakin University campus in Waurn Ponds and testing was done on the same asphalt surface on two different test days. Figure 2 shows the surface that was tested on during both days of testing.

Figure 2. Asphalt test surface at Nicol Drive South

The test conditions for each of the asphalt test days are given in Table 1. Testing was conducted over two days to determine if there was variation from test day to test day from road and atmospheric conditions. The two days selected were similar in temperature and cloud cover but different in humidity levels.

Table 1. Asphalt test conditions.

Identifier	Test Date	Temperature (°C)	Humidity (%)	Cloud	Location
Asphalt test day 1	02/12/2020	16-18	46-58	Partially cloudy	Nicol Drive South Waurn Ponds, 3216
Asphalt test day 2	08/12/2021	15-18	64-67	Partially cloudy	Nicol Drive South Waurn Ponds, 3216

2.4.2 Single aggregate chip seal surfaces

The rural network of B and C roads in Victoria are predominately made up of chip seals where only a single aggregate size has been used. The two common aggregate sizes are 10mm and 14mm. This measurement is the mean aggregate size used in the surface. The roads for this study were selected to give an understanding of the abrasion damage caused by different sized aggregate and different levels of wear (damage/wear of the road from use). The wear studies were conducted on 10mm chip seal surfaces as suitable surfaces were present in the test area to test the hypothesis. Three road locations were used for testing with images of each of these surfaces given in Figure 3. The first was a newly laid surface, the second had seen two years of use since it had been laid and the third was an older surface that had been in place for more than ten years. The details of the testing days are given in table 2.

For the 14mm chip seal surfaces, two roads of similar age were selected to understand the repeatability of abrasion damage from one road location to another. These results also were used to provide a suitable comparison surface for the new 10mm chip seal. Images of the surfaces of these two roads are given in Figure 4. The details of the testing days are given in table 2.

New surfaces were preferred as they provide a worst-case scenario for abrasion damage. Road surfaces were selected so that they did not have damage to the seal and were relatively flat over the test area. For the worn 10mm chip seal surfaces the path of the test head was selected so that there were no patches of tar bleed in the abrasion surface.

Table 2. Single aggregate chip seal test conditions.

Identifier	Test Date	Temperature (°C)	Humidity (%)	Cloud	Location
10 mm chip seal (C119)	31/03/2021	15-22	61-85	Partially cloudy	Birregurra Rd at Darcys Rd Birregurra (C119)
10 mm chip seal (C155)	11/03/2021	15-23	55-79	Sunny	Colac-Lavers Hill Rd at Frys Rd Gellibrand (C155).
10 mm chip seal (C152)	30/03/2021	14-20	50-77	Partially cloudy	Warncoort-Birregurra Rd at Bushy Park Rd, Warncoort (C152)
14 mm chip seal (C119)	13/04/2021	11-17	58-87	Cloudy	Birregurra Rd at Darcys Rd Birregurra (C119)
14 mm chip seal (C152)	17/03/2021	16-22	65-82	Sunny	Warncoort-Birregurra Rd at Bushy Park Rd, Warncoort (C152)

Figure 3. Images of the 10mm single aggregate chip seal surfaces.

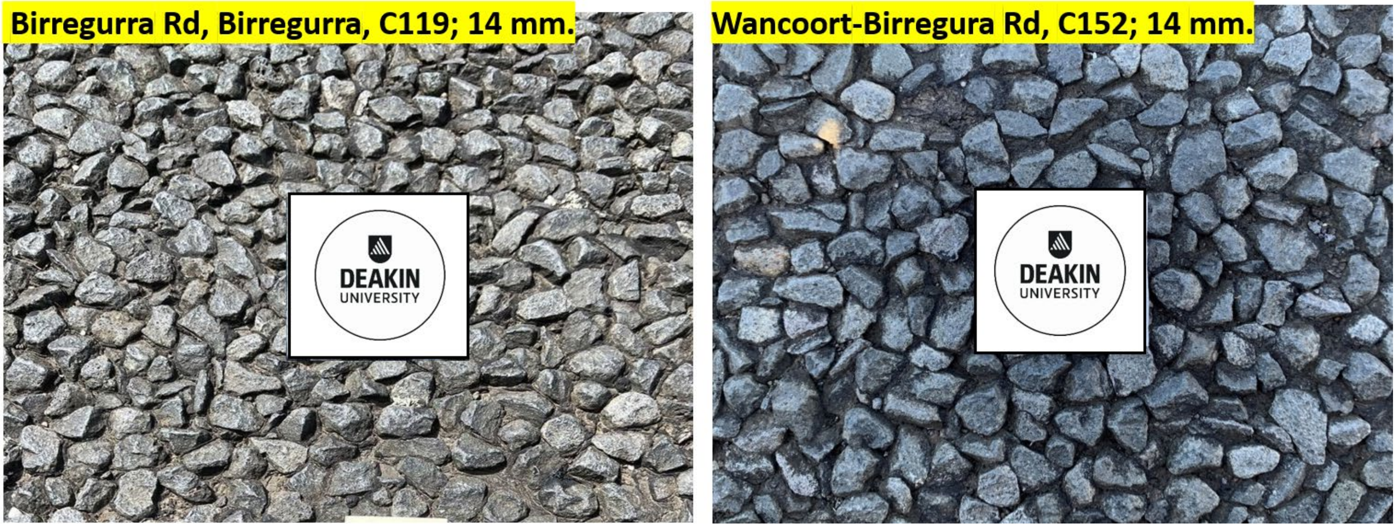


Figure 4. Images of the 14mm single aggregate chip seal surfaces.

2.4.3 Multi aggregate chip seal road surfaces

Four different multi aggregate surfaces were evaluated. Two of these surfaces were dual aggregate with one being a 14/7 mm chip seal on the M1 and the other being a 20/7 mm chip seal also at the M1 test location. A second 14/7 mm chip seal was done however this was a multi-layer surface that was made up of a 10mm chip seal covered by a geotextile reinforcement layer and then the 14/7 mm chip seal (GRS). This resulted in a very flat road surface. The last multi aggregate surface was a 20/7/7 mm multi aggregate chip seal tested at the M1 test location. This seal was a 7mm chip seal surface covered with a 20mm aggregate and the overfilled with a 7mm aggregate. Images of each of the road surfaces are given in Figure 5.

The aim of this part of the study was to determine the effect that mean aggregate size had on abrasion in multi aggregate road surfaces. The GRS and 20/7/7 surfaces were studied as these were two trial surfaces being evaluated for use in the Victorian network. All four of these surfaces were on a busy multilane motorway that had seen significant traffic since laying two years earlier. The aggregate was noticeably rounded on its edges especially the large aggregate pieces in the 20/7 and 20/7/7 surfaces. The chip seal surfaces were all relatively worn in the wheel tracks, so testing was conducted down the centre of the lane. The images given in figure 5 represent the road surface on the test path of the test head down the centre of the lane.

Table 3. Multi aggregate chip seal test conditions.

Identifier	Test Date	Temperature (°C)	Humidity (%)	Cloud	Location
14/7 mm chip seal (M1)	2/03/2021 9/03/2021	15-17 17-20	50-63 59-76	Clear Sunny	East bound Princes Hwy east of Drapers Rd, Colac(M1)
20/7 mm chip seal (M1)	26/02/2021	16-18	45-52	Partially cloudy	East bound Princes Hwy east of Drapers Rd, Colac(M1)
14/7 mm GRS chip seal (M1)	1/03/2021	19-22	39-54	Partially cloudy	East bound Princes Hwy east of Drapers Rd, Colac(M1)
20/7/7 mm chip seal (M1)	12/02/2021	20-24	50-60	Cloudy	East bound Princes Hwy east of Drapers Rd, Colac(M1)
20/7 mm chip seal (C421)	30/06/2021	12-16	59-82	Clear	Koo-WeeRup-Longwarry Rd at Heads Rd, Bayles (C421)
20/7/7 mm chip seal (C421)	29/06/2021	9-15	55-72	Clear	Koo-WeeRup-Longwarry Rd at Heads Rd, Bayles (C421)

Figure 5. The images of the multi-aggregate road.

The test results on the 20/7/7mm multi-aggregate chip seal surface (M1) suggested that motorcycle clothing was quicker to fail with this type of surface. A second surface was located and testing was conducted to provide a further understanding of the abrasion performance of this type of road surface. A newly laid trial patch of the 20/7/7 and a 20/7 chip seal surfaces were located on the Koo Wee Rup-Longwarry Rd. The image of these surfaces is shown in Figure 6. These road surfaces were on a single lane road, had only been laid for several months and had seen very little traffic since laying. The Princes Hwy surface by contrast was on a multi lane road, had been laid for 2 years and had seen significant traffic resulting in a flattened of the surface and rounding of sharp edges on the aggregate (Figure 5). By contrast the new 20/7/7 and 20/7 surfaces had a large number of randomly distributed 20mm aggregates sitting proud of the road surface. These appeared to be quite angular on their edges and were close to cubical in shape. Details of the test conditions are given in table 3.

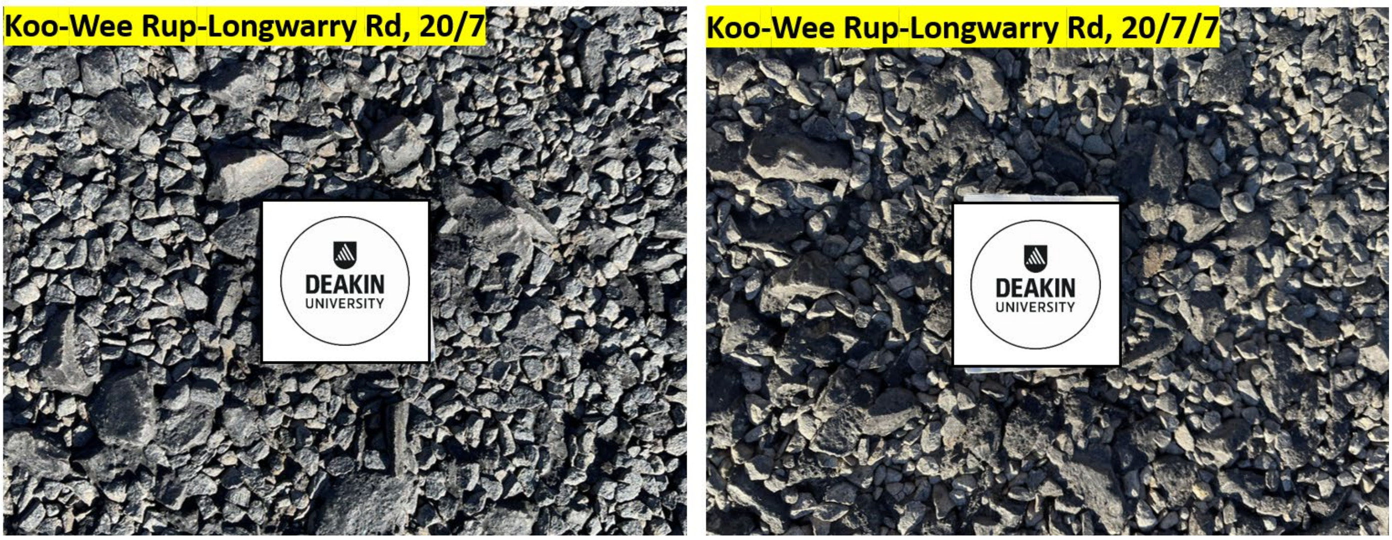


Figure 6. The images of Koo Wee Rup-Longwarry Rd surfaces.

3 Results and discussion

3.1 Laboratory testing

The corrected results for each of the test samples given in table 4 are the same as would be reported for the fabric if tested for MotoCAP. The coefficient of variation (CV%) for the single layer textile structures were higher than for the protective denim and leather. Textile fabrics have a very high directional effect on fabric abrasion performance. Tests done at 45° to the belt typically have lower abrasion performance and this increases test variation. The leather is less effected as the material is more uniform in each direction of the hide. The two layers of fabric of the protective denim also reduces the CV%.

Table 4. Corrected abrasion times for each fabric under standard test conditions

Test direction → Fabric type	0° (s)	45° (s)	90° (s)	0° (s)	45° (s)	90° (s)	Mean (s)	St. Dev. (s)	CV% (%)
600D polyester (D)	0.40	0.39	0.34	0.38	0.31	0.46	0.38	0.05	12.4
500D nylon (N1)	0.48	0.33	0.36	0.55	0.40	0.40	0.42	0.07	17.7
1600D nylon (N2)	1.11	0.92	1.08	1.10	0.85	1.35	1.07	0.16	14.9
Leather	3.72	3.28	3.74	3.21	3.92	3.15	3.50	0.30	8.6
Protective Denim	2.98	2.60	2.79	3.4	3.15	3.25	3.03	0.27	9.0

To reduce test variation testing in the on-road abrasion trials, all tests were conducted in the zero direction only. Testing is the laboratory was repeated with each of the samples tested five times (Table 5) in the 0° degree test direction. The results were slightly higher for all of the textile samples. This was expected as the 45° degree test direction normally has a lower test score in textile materials due to the orientation of yarns in the structure. The 500D Nylon had a higher CV% in its test result than the other materials tested due to the thin nature of the fabric and the propensity for the fabric structure to be partially damaged during initial impact with the abrasive belt. Variation in the levels of this initial damage leads to higher CV% values in the test scores.

Table 5. Raw abrasion times for each fabric in the 0° degree test direction

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	Mean (s)	St. Dev. (s)	CV% %
600D polyester (D)	0.46	0.44	0.41	0.43	0.45	0.44	0.02	3.9
500D nylon (N1)	0.52	0.55	0.48	0.37	0.38	0.46	0.07	15.9
1600D nylon (N2)	1.20	1.19	0.95	1.21	1.08	1.13	0.10	8.8
Leather	3.91	3.33	3.43	3.40	3.62	3.54	0.21	5.9
Protective Denim	3.18	3.63	3.57	3.33	3.76	3.49	0.21	6.0
Standard fabric	2.59	2.63	2.71	2.51	2.69	2.63	0.07	2.7

3.2 Asphalt surface

3.2.1 Asphalt test day 1

The whole test was run quickly and finished within 4 hours as the road surface had limited macrostructure, and it did not damage the underneath protective leather fabric. However, the double layer protective denim fabrics were replaced several times due to being holed at the end of the abrasion test. The CV% of the asphalt tests were higher than those measured in the laboratory. In the laboratory the abrasive belt is both flat and uniform in its abrasive nature. The asphalt road surface tested on was visually flat however if an accelerometer was to be connected to the test head there would be a number of times where surface imperfections would push into the test sample. These occur from individual rocks sitting proud of the surfaces or due to dips/bumps in the road surface. The randomness of these loading events results in increased variation in the time to hole results.

The coefficient of variation (CV), for all materials was less than 30%, which indicated that the test results were quite consistent due to the even road surface and the stable weather condition. The denim fabric displayed the longest abrasion time (15.97 S), which was closely followed by the leather fabric (14.24 S) (Table 6). The worst abrasion resistance was observed for 600D Polyester (P) and 500D Nylon (N1) fabrics, respectively.

Table 6. Abrasion times for day 1 of testing on asphalt.

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	1.16	1.24	1.58	1.45	2.15	1.37	1.49	0.32	21.7%
500D Nylon (N1)	1.29	0.81	1.60	1.65	2.33	1.81	1.58	0.47	29.4%
1600D Nylon (N2)	2.67	1.99	2.46	3.09	3.45	2.88	2.76	0.46	16.8%
Leather	17.03	16.25	11.57	10.73	14.14	15.73	14.24	2.36	16.6%
Protective Denim	13.46	14.63	15.95	15.14	18.81	17.81	15.97	1.84	11.5%
Standard fabric	8.68	11.03	9.84	12.73	12.52	11.57	11.06	1.43	13.0%

3.2.2 Asphalt test day 2

Table 7 shows the abrasion time for each fabric in the 0°degree test direction. The mean abrasion time followed the same trend as those in Table 4 but with a slightly higher value. The obtained higher abrasion time in the second test day might be due to the higher ambient humidity (64-67%) compared to the first day (46-58%). The test results for each fabric were quite consistent (CV<33%) showing the protective denim fabric performed better against abrasion among other fabrics.

Table 7. Abrasion times for day 2 of testing on asphalt.

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	2.10	2.69	2.49	2.17	3.19	2.64	2.55	0.36	14.2%
500D Nylon (N1)	3.40	2.62	2.72	2.67	2.75	2.12	2.71	0.37	13.8%
1600D Nylon (N2)	5.00	5.84	3.84	3.92	1.58	3.63	3.97	1.32	33.2%
Leather	15.75	26.52	14.08	19.57	15.54	18.35	18.30	4.11	22.4%
Protective Denim	19.87	29.01	20.79	18.25	19.40	19.09	21.07	3.63	17.2%
Standard Fabric	11.89	16.30	9.09	12.14	12.81	13.22	12.58	2.13	16.9%

3.2.3 Asphalt analysis

The abrasion times observed on the asphalt surface were different for each of the test days (Figure 7). These differences could have been caused by atmospheric conditions as temperature and humidity will alter the mechanical properties of textile and leather materials. The higher humidity levels were the key factor resulting in the increased abrasion times achieved on day 2. The structure of natural and synthetic materials such as the ones used in this research mean that when moisture enters the fibre it will have an effect on the length and diameter. The addition of moisture can also change the hydrogen bonding crosslinking of polymer chains which in turn can alter mechanical properties. Moisture content of the materials results in swelling of fibres that would make it harder to pull them from the materials during abrasion. The increased moisture levels would also result in changes to fibre elasticity as polymer chain crosslinking is reduced making it more likely that fibres would stretch rather than break during interactions with the hook points on the road surface.

These asphalt test results highlight the need for further testing to occur on the same road surface under different temperature conditions. Earlier work with a small number of tests on a wet surface have indicated that moisture may increase abrasion times. The water was believed to cool and lubricate the fibres at the abrasion interface on an asphalt surface extending the time to hole. It is felt that water may not have as much of an effect on a chip seal road compared to asphalt in extending the time to hole as abrasion is more from fibre removal rather than surface damage. As only a small number of tests were conducted on the wet surface due to changing weather conditions further testing is required to verify and quantify this finding.

Temperature may also have an effect on abrasion times. Riding air temperatures in Victoria can vary from -2 to 40+°C but are typically 10-35°C. Higher temperatures could increase the abrasion temperatures reached and result in earlier failure of protective clothing. This may be more likely with thermoplastic polymeric materials such as nylon and polyester. The temperature was similar for both days of testing conducted in this work so it is believed that this was not the reason for the different abrasion times. Further testing is required to quantify how much effect temperature has on abrasion resistance and to determine if some materials are affected more than others.

The asphalt surface at Nicol Drive South performed at a similar level to that observed on a similar asphalt surface that testing was conducted on at Pullman Park in Auckland, New Zealand. These results only show the abrasion times for two different asphalt surfaces. Further abrasion testing is required on different asphalt surfaces to ensure that there are no surfaces that may be more abrasive.

The abrasion times recorded on asphalt were on average 4.4 times longer than those measured on the laboratory test machine. The higher denier nylon (1600D nylon) was consistently less than the other test materials at 2.8 times. There had been melting of the polymer during abrasion of the 1600D nylon samples as shown by lumps of polymer present at the abrasion interface after testing. It is possible that premature failure of the abrasion surface occurred due to melting of the fibres. This was prevalent in the thicker nylon as sliding times were longer allowing increased heat generation at the abrasion surface. This was not evident in the leather, protective denim and standard fabric samples as the materials these were made from do not melt or significantly change properties at higher temperatures. More work is required to quantify the temperatures occurring at the abrasion surface interface and to determine if thermoplastic protective clothing is vulnerable to premature failure due to melting.

The predominate road surface used in an urban environment is asphalt. The longer abrasion times achieved on asphalt surfaces could allow for a wider range of clothing to be available for riders in an urban environment. An example would be to take a garment that has a 1 second abrasion time on the Cambridge machine. This would provide 4.4 seconds of abrasion time on asphalt using the 4.4 multiplier. Under the worst-case scenario observed for the 1600D nylon where there was only a 2.8 multiplier this would still be 2.8 seconds of protection. 2.8 seconds of abrasion time equates to 22 meters of sliding distance before a hole is formed. This would be suitable for an urban environment where asphalt was the predominant surface and riding speeds are 60km/hr or less.

The differences between the laboratory Cambridge impact abrasion tester used for MotoCAP and asphalt surfaces would support messaging that two-star or better clothing would be suitable for an urban environment. This would be especially important for marketing to gig economy workers and scooter riders.

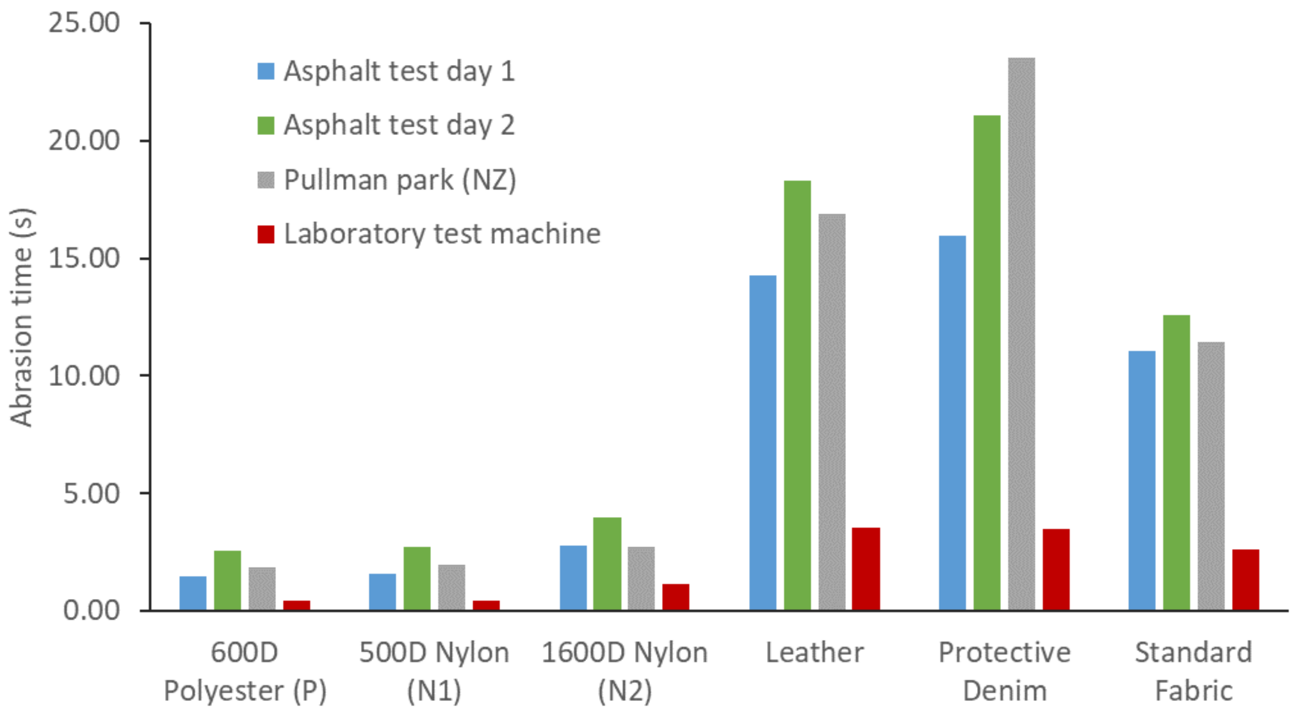


Figure 7. Abrasion performance of the different material combinations on asphalt surfaces and the laboratory test machine.

3.3 Single aggregate chip seal surfaces

3.3.1 10 mm chip seal (C119)

This 10mm chip seal road surface was selected as a new surface as it was laid within six months of the test being conducted. The measured abrasion times for each fabric are given in Table 8.

Table 8. Abrasion times for C119 10 mm chip seal surface.

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	0.23	1.45	0.31	0.52	0.64	0.30	0.58	0.42	72.3%
500D Nylon (N1)	0.80	1.23	0.15	0.96	0.15	0.75	0.67	0.40	59.5%
1600D Nylon (N2)	0.50	2.40	1.79	1.31	1.34	1.19	1.42	0.58	40.8%
Leather	3.03	1.88	3.58	3.61	1.23	2.77	2.68	0.87	32.4%
Protective Denim	2.32	2.36	2.47	3.2	3.27	1.95	2.60	0.48	18.5%
Standard Fabric	3.07	1.18	2.12	1.42	2.53	1.55	1.98	0.66	33.6%

3.3.2 10 mm chip seal surface (C155)

This 10mm chip seal road surface was selected as a moderately worn surface as it was laid two years before the test being conducted. The measured abrasion times for each fabric are given in Table 9.

Table 9. Abrasion times for the C155 10mm chip seal surface.

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	0.15	0.15	0.42	0.44	0.15	0.35	0.28	0.13	46.8%
500D Nylon (N1)	0.80	0.55	0.31	0.60	0.38	0.31	0.49	0.18	36.1%
1600D Nylon (N2)	0.93	0.23	0.28	0.82	1.49	0.25	0.67	0.46	69.4%
Leather	2.80	2.37	0.42	1.60	2.56	4.70	2.41	1.29	53.7%
Protective Denim	2.31	1.64	1.55	3.60	3.39	2.67	2.53	0.79	31.1%
Standard Fabric	2.15	1.45	1.55	3.22	2.49	1.26	2.02	0.68	33.8%

3.3.3 10 mm chip seal surface (C152)

This 10mm chip seal road surface was selected as a heavily worn surface as it was laid ten plus years before the test being conducted. There was minor tar bleed evident in some places on the road but not in the path of the test head during testing. The test results are given in Table 10.

Table 10. Abrasion times for C152 10 mm chip seal surface.

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	0.77	1.1	1.17	0.43	0.61	1.13	0.87	0.28	32.6%
500D Nylon (N1)	0.91	0.75	1.52	0.43	1.06	0.64	0.89	0.35	39.1%
1600D Nylon (N2)	2.07	1.96	3.99	1.48	1.91	1.45	2.14	0.86	40.1%
Leather	6.99	4.61	2.77	8.31	3.6	2.51	4.80	2.16	45.0%
Protective Denim	5.83	7.13	2.31	4.47	7.04	5.35	5.36	1.65	30.8%
Standard Fabric	4.59	3.5	5.18	3.23	3.5	5.75	4.29	0.95	22.1%

3.3.4 10mm chip seal analysis

The moderately worn surface of C155 did not provide longer abrasion times than the almost new surface of C199 (Figure 8). Whilst the C155 was laid two years before testing, the road had not seen the levels of traffic like those that were observed on the similarly aged Princes Highway surfaces. This combined with the fact that the track of the abrasion test head was down the middle of the lane where there is very little wheel traffic meant that abrasion times were similar to those seen on the new 10mm chip seal surface of C199.

In all but the 500D nylon the heavily worn chip seal surface of C152 saw longer abrasion times than those of the laboratory test machine. This was expected as the aggregate over time had been pushed into the tar surface resulting in a very flat finish with minimal exposed aggregate points. There appeared also to have been a rounding of aggregate points over time that would have contributed to the better abrasion results. The results of this surface would indicate that abrasion damage reduced as a surface was used.

The levels of variation in test results increased for a number of the materials tested on chip seal when compared with asphalt and in the laboratory. The key reason for the change in variability of testing results was the damage done to the sample on initial impact with the road surface. The sharp points of the road surface combined with the initial impact of the test head into the road surface caused cutting damage of the material. The height, number and sharpness of the points have an effect on cutting damage. This was observed in the higher CV% values for the C199 and C155 surfaces compared with the heavily worn C152. The rounding of the points reduced the risk of earlier abrasion failure which also had an effect on reducing the rate of abrasion damage done by the surface. The single layer materials of nylon, polyester and leather were more prone to damage in this way as the cutting damage weakened their structure. The two multi layered materials (protective denim and standard fabric) only suffer damage to the outside layer on the 10mm chip seal and did not have the same variability in measurement.

The abrasion times for each of the 10mm chip seals and the laboratory test machine were all quite similar to each other. The abrasion times achieved in the laboratory are a good indicator of the garment's performance on this type of surface.

Higher travel speeds on a rural road combined with a higher rate of abrasion from the chip seal surface indicate that increased abrasion protection is required when riding in this environment. Higher travel speeds result in a longer sliding distance during a crash. This increases the risk of abrasion damage. As the abrasion times for the chip seal were the same as those for the abrasion tester, a four second test time should result in protection for a 32 meter slide of chip seal. To give riders advice on the appropriate clothing for a rural environment the MotoCAP protection rating can be used. Two protection stars can be achieved by lower abrasion performing garments with good impact protectors and seam strength. To achieve three protection stars a garment must have abrasion protection with a rating of 3/10 or higher. This level of abrasion protection is equivalent to 2.5+ seconds of abrasion time in the high-risk part of the garment. This is starting to achieve the minimum requirements for abrasion protection for a chip seal road. This makes the MotoCAP message simple: "When riding in a rural environment, a garment of three protection stars or better would best be worn by riders.

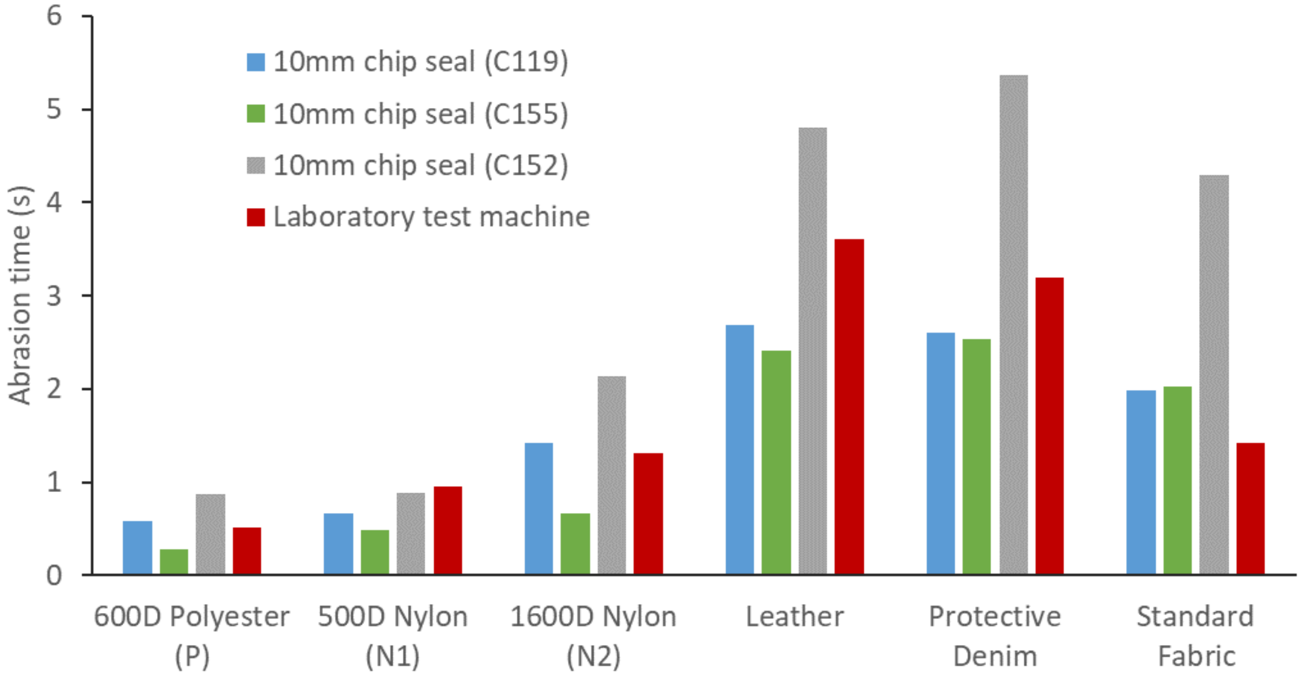


Figure 8. Abrasion performance of the different material combinations on 10mm chip seal surfaces and the laboratory test machine.

3.3.5 14 mm chip seal (C119)

This 14mm chip seal was selected as it was constructed from a single aggregate size and was quite new. The results of this testing are given in Table 11.

Table 11. Abrasion times for C119 14 mm chip seal surface.

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	0.74	0.15	0.17	0.15	0.35	0.25	0.30	0.21	69.1%
500D Nylon (N1)	0.47	0.15	0.25	0.17	0.25	0.62	0.32	0.17	53.4%
1600D Nylon (N2)	0.12	0.65	0.2	0.78	0.54	0.45	0.46	0.23	51.2%
Leather	2.75	1.96	1.22	2.6	1	1.75	1.88	0.65	34.4%
Protective Denim	2.5	1.19	0.28	1.08	1.08	0.46	1.10	0.71	64.9%
Standard Fabric	2.85	2.42	1.68	0.68	0.8	0.98	1.57	0.83	52.7%

3.3.6 14 mm chip seal (C152)

This 14mm chip seal road surface was selected to provide a second set of results for a new 14mm chip seal surface. It had a similar surface quality to the C119 14mm chip seal. The results of this testing are given in Table 12.

Table 12. Abrasion times for C152 14 mm chip seal surface.

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	0.2	0.69	1.3	0.87	0.95	0.48	0.75	0.35	46.8%
500D Nylon (N1)	0.88	1.14	0.33	0.82	0.56	0.66	0.73	0.26	35.0%
1600D Nylon (N2)	0.99	0.63	1.81	0.77	1.37	2.07	1.27	0.53	41.6%
Leather	1.11	3.21	1.9	0.82	0.56	1.34	1.49	0.88	58.8%
Protective Denim	4.83	5.61	2.77	3.03	3.49	8.02	4.63	1.82	39.3%
Standard Fabric	2.13	3.07	1.66	2.36	1.29	1.84	2.06	0.57	27.5%

3.3.7 14mm chip seal analysis

The abrasion times for each of the 14 mm chip seals and the laboratory test machine were all quite similar to each other (Figure 9). The times for the 14 mm chip seal were similar to those seen on the 10mm chip seal and would indicate that aggregate size has very little influence on a well rolled and laid single aggregate size road surface.

The level of variation was higher in the 14 mm chip seals than in the 10mm chip seals. The road surface macrostructure would be larger due to the larger aggregate size. This would result in increased penetration into the protective clothing test sample and subsequent increased possibility of damage to the sample. The C119 14 mm chip seal surface had lower abrasion times and higher CV% values and was more affected by this sample cutting.

As with the 10 mm chip seal surface the abrasion times achieved in the laboratory were a good indicator of the garment's performance on a 14 mm chip seal surface. These results clearly highlight for MotoCAP that when riding in a rural environment, a garment of three stars or better protection performance would best be worn by riders.

The results of these tests would suggest that both 10 and 14 mm single aggregate chip seal surfaces have a similar damage rate for motorcycle clothing. In single aggregate size chip seal, mean aggregate size had little effect on the time to hole for clothing. Both are suitable for use on high motorcycle use roads.

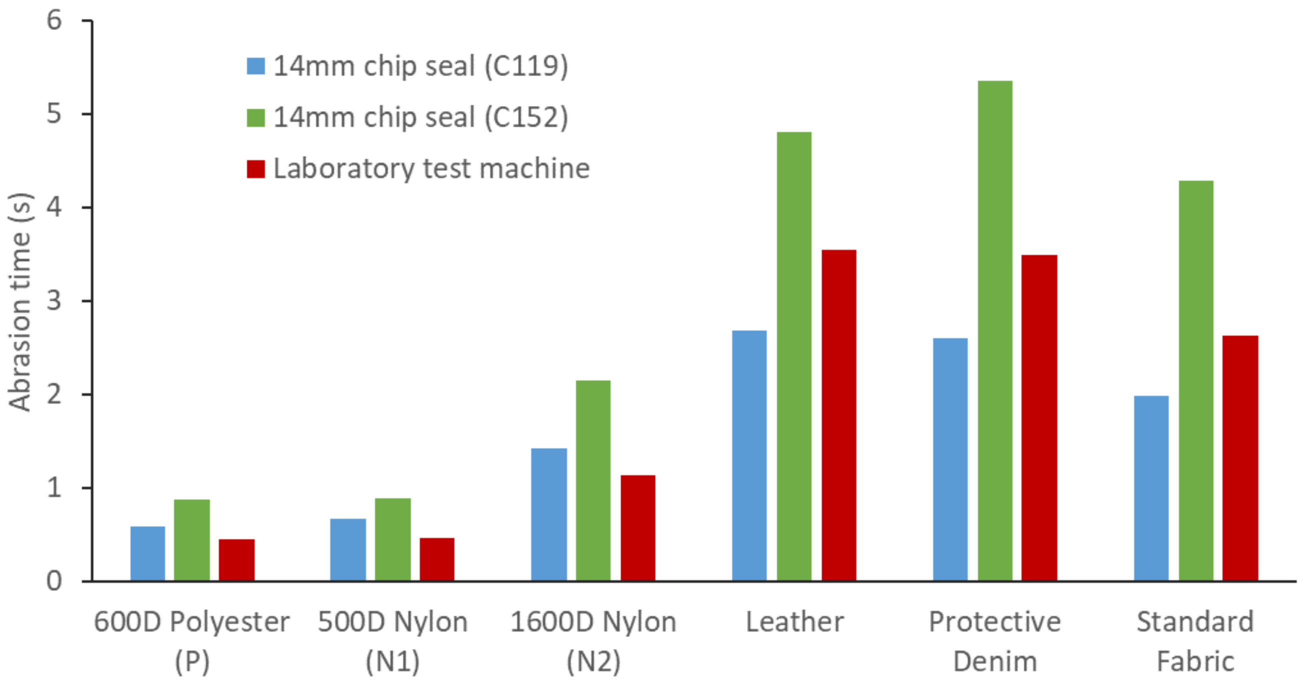


Figure 9. Abrasion performance of the different material combinations on 14mm chip seal surfaces and the laboratory test machine.

3.4 Multi aggregate chip seal road surfaces

3.4.1 14/7 chip seal surface (M1)

The test surface was a 14/7mm chip seal surface laid on the east bound slow lane of the Princes Hwy (M1) east of Colac. This testing was conducted over two days. The results from these two dates of testing are shown in Table 13. The obtained results were relatively consistent and there was no observable difference between the two test days.

Table 13. Abrasion times for the M1 14/7 chip seal surface

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	2.71	2.30	1.60	0.41	0.98	1.37	1.56	0.77	49.4%
500D Nylon (N1)	2.36	0.75	0.67	0.61	0.35	0.71	0.91	0.66	72.9%
1600D Nylon (N2)	2.05	0.54	2.54	2.50	2.72	2.32	2.11	0.73	34.7%
Leather	5.19	2.54	2.17	5.24	3.63	1.42	3.37	1.46	43.4%
Protective Denim	3.53	1.60	0.98	1.71	3.16	5.50	2.75	1.52	55.4%
Standard Fabric	1.73	1.39	2.50	3.68	3.60	2.30	2.53	0.86	34.0%

3.4.2 20/7 chip seal surface (M1)

The test surface was a 20/7mm chip seal surface laid on the east bound slow lane of the Princes Hwy (M1) east of Colac. The surface was perfectly flat over the full length of the test area. The measured abrasion time for each fabric is given in Table 14.

Table 14. Abrasion times for the M1 20/7 chip seal surface

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	1.08	0.17	0.43	0.54	0.51	0.15	0.48	0.31	64.3%
500D Nylon (N1)	0.69	1.65	0.15	1.86	0.80	0.82	1.00	0.58	58.8%
1600D Nylon (N2)	2.02	1.73	0.28	1.71	0.49	1.89	1.35	0.70	51.4%
Leather	0.64	3.42	6.41	0.72	2.38	2.46	2.67	1.94	72.6%
Protective Denim	0.67	4.41	2.67	1.84	1.42	0.93	1.99	1.26	63.3%
Standard Fabric	2.85	1.34	5.01	0.85	2.05	1.63	2.29	1.37	59.7%

3.4.3 14/7 GRS chip seal surface (M1)

The test surface was a 14/7 GRS chip seal surface laid on the east bound slow lane of the Princess Hwy (M1) east of Colac. It was drizzling early in the morning for half an hour before the test began. The ambient humidity had sharply decreased from 90% in the morning to 54% when the test was started and gradually declined to 39% at the end of the test. The ambient temperature was 19-22°C during the testing. The wind speed during the entire test was high and around 26-30 km/h based on the weather forecast data. The road surface was slightly moist for the first tests. The measured abrasion time of all samples is given in Table 15.

Table 15. Abrasion times for the M1 14/7 GRS chip seal surface

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	1.94	0.77	1.53	1.11	0.15	2.03	1.26	0.66	52.7%
500D Nylon (N1)	1.00	0.15	0.69	1.99	1.02	0.95	0.97	0.55	56.6%
1600D Nylon (N2)	1.99	2.77	1.96	2.45	1.89	2.58	2.27	0.34	15.0%
Leather	8.60	7.66	5.22	4.31	4.64	5.28	5.95	1.60	26.9%
Protective Denim	5.40	5.92	5.75	8.42	6.31	7.69	6.58	1.10	16.7%
Standard Fabric	4.26	6.66	5.36	6.42	6.64	5.68	5.84	0.86	14.7%

Whilst the road was damp at the start of testing it dried quite quickly under the wind and warmer air temperatures. Previous work with this test device in a wet environment on asphalt had observed an increase of abrasion times for a damp road when compared with a dry road. This was not replicated here with abrasion times being relatively consistent over the period of testing.

The 14/7 GRS road surface was much smoother than the 14/7 chip seal surface without the GRS. The testing progressed faster than the other 14/7 surface as there was less damage to the layer of leather and denim fabrics present to protect the test head from damage. The results were more consistent, and this was represented in the lower CV% results and longer abrasion times for the leather, protective denim and standard fabrics. An example of this was the leather material where the abrasion time increased to 5.95 s with a reduced CV% of 26.9 % for the GRS (3.37 s and a CV% of 43.4% for the 14/7). The change in surface had a negligible effect on the abrasion times of the polyester and nylon fabrics.

3.4.4 Multi aggregate chip seal road surfaces analysis

The abrasion times for the 14/7 and 20/7 dual aggregate chip seals were similar to each other when tested (Figure 10). The 20/7 had slightly shorter times to hole than the 14/7 over most of the test samples. The 14/7 that had been laid over a 10mm chip seal and GRS was far less abrasive for the leather, protective denim and standard fabrics. This road was much flatter in appearance which may have been from the pushing in of the larger stones into the multi-layer surface beneath them. These samples were less likely to be damaged on impact resulting in longer abrasion times.

The results of these tests would suggest that for partially worn surfaces both 14/7 and 20/7mm dual aggregate chip seal surfaces have a similar damage rate for motorcycle clothing with the 14/7mm performing slightly better than the 20/7mm. Where a dual aggregate surface was required for surface durability on a high motorcycle use road the 14/7mm was a better choice than the 20/7. For high surface durability on straight sections of road the 14/7mm GRS was the best alternative.

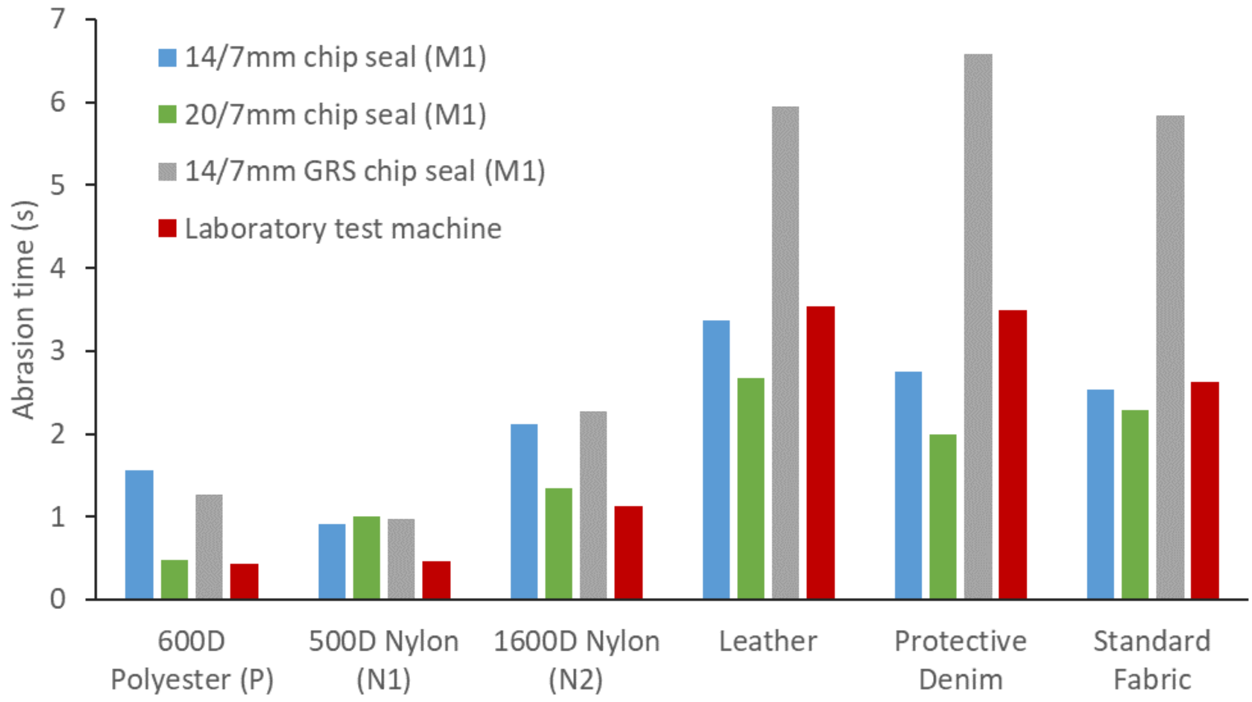


Figure 10. Abrasion performance of the different material combinations on multi aggregate chip seal surfaces and the laboratory test machine.

3.4.5 20/7/7 chip seal surface (M1)

The test surface was a 20/7/7mm chip seal surface laid on the east bound slow lane of the Princes Hwy (M1) east of Colac. The results of the tests are given in Table 16.

Table 16. Abrasion times for the M1 20/7/7 chip seal surface

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	0.98	1.68	1.13	0.15	0.28	0.32	0.76	0.55	72.9%
500D Nylon (N1)	0.33	0.59	0.46	0.17	0.72	0.26	0.42	0.19	45.1%
1600D Nylon (N2)	0.98	0.46	1.03	0.46	1.13	0.45	0.75	0.30	39.7%
Leather	1.45	0.38	0.56	0.28	0.17	0.15	0.50	0.45	89.8%
Protective Denim	1.51	1.81	1.89	0.77	1.33	1.48	1.47	0.37	25.0%
Standard Fabric	2.05	2.57	2.33	0.95	3.23	1.17	2.05	0.79	38.4%

The test was done in 7 hours since the under layer protective leather fabric was changed almost after each one or two tests. The surface had a small distribution of aggregates sitting proud of the majority of the road surface. These were found to point load test samples and damage fabrics instantly after releasing the test head. The failure mechanism was a point damage deep into the test head often penetrating the test sample, the two layers of denim under the test sample and the leather layer on the face of the aluminium test head. This then resulted in a hole forming from tearing of, at least the outside layer of protective material.

The observed high CV percent for all fabrics and the number of very low test times (<0.3 seconds) confirmed this claim. The leather material was one of the materials more likely to fail in this manner. The penetrating aggregate would go on to tear the leather layer open forming a large hole and exposing the stop wire of the test. The two-layer protective denim and standard fabric samples were less likely to fail as quickly on this surface. This might be due to the second layer not being damaged as much as the first during this impact event. After surviving the initial impact, the second layer would go on to provide abrasion protection.

An example of the types of damage occurring when the road surface tore open the outer surface is shown in Figure 11. The level of damage seen on the cotton canvas standard fabric shows the abrasion energy involved from this road surface. Typical abrasion samples would have a round hole with a beard of fibres on the leading edge of the abrasion sample. The denim and leather samples both show characteristic torn open failure edges on the leading edge of the test sample.

The results of these tests would suggest that 20/7/7mm multi aggregate chip seal surfaces displayed increased failure risks to all types of motorcycle clothing that would most likely result in an increased injury risks to motorcyclists in the advent of a crash.

a b c

Figure 11. (a) canvas standard fabric, (b) protective denim and (c) leather abrasion samples after impact abrasion damage on the 20/7/7 chip seal surface.

3.4.6 20/7 chip seal surface (C421)

Testing was conducted at the Koo-WeeRup-Longwarry Rd, (C421) on a newly laid 20/7 mm chip seal surface. This road surface was far newer than the 20/7 chip seal surface tested on the Princes Highway detailed in section 3.4.2. As seen in Figure 6 the road surface had many large sharply edged stones almost cubical in shape sitting proud of the 7mm surface aggregate. These had the same effect as was discussed in section 3.4.4 where the test materials were point loaded causing premature failure. The premature failure is evident in the high (CV% > 50%) coefficient of variation values for all of the test samples tested on this surface (Table 17).

Table 17. Abrasion times for the C421 20/7 chip seal surface.

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	0.15	0.59	0.62	0.25	0.46	0.15	0.37	0.20	52.9%
500D Nylon (N1)	0.52	0.15	0.72	0.46	0.28	0.15	0.38	0.21	54.5%
1600D Nylon (N2)	0.88	0.62	0.28	0.39	0.28	1.03	0.58	0.29	50.3%
Leather	0.15	0.66	0.77	1.19	0.35	0.15	0.55	0.37	68.2%
Protective Denim	0.96	1.47	0.12	0.95	0.28	0.43	0.70	0.47	66.6%
Standard Fabric	0.69	1.5	0.56	0.35	1.45	1.34	0.98	0.46	47.0%

The worn surface of the 20/7 tested on the Princes Highway was less abrasive in all cases than the new surface (Figure 12). The new C421 20/7 was more abrasive than the laboratory machine in all protective material cases. All material types only had a small number of samples that did not burst open on impact with the new C421 20/7 surface.

The results of these tests would suggest that 20/7mm dual aggregate chip seal surfaces displayed increased failure risk to all types of motorcycle clothing that would most likely result in an increased injury risk to motorcyclists in the advent of a crash. This 20/7mm surface had seen far less traffic since installation than the surface discussed in 3.4.2 and had a more pronounced macrostructure. The increased damage was caused by the dual level structure resulting from the 20mm aggregate sitting proud of the 7mm aggregate. The use of this surface on high motorcycle use roads should be avoided unless no alternative is available. Alternative surfaces available are 14/7mm, 14/7 GRS and asphalt.

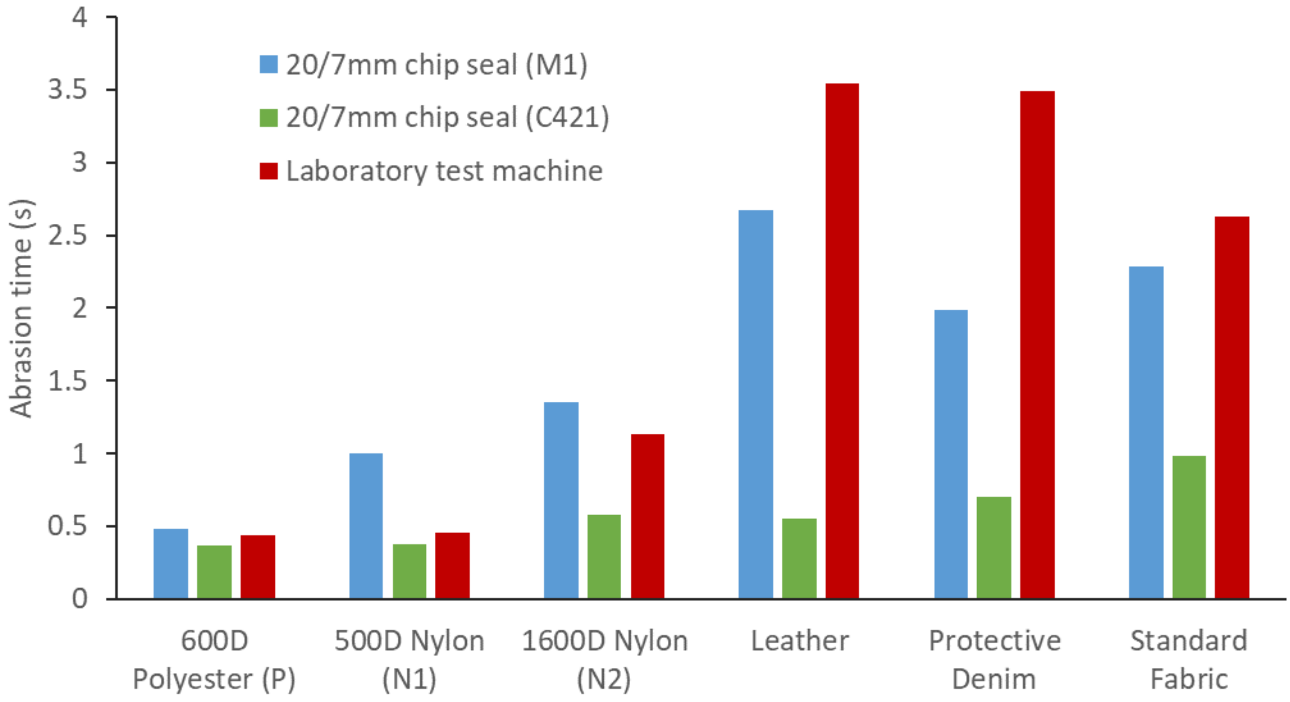


Figure 12. Abrasion performance of the different material combinations on 20/7mm chip seal surfaces and the laboratory test machine.

3.4.7 20/7/7 chip seal surface (C421)

Testing was conducted at the Koo Wee Rup-Longwarry Rd, (C421) on a newly laid 20/7/7 multi aggregate chip seal. This road surface was far newer than the 20/7/7 chip seal surface tested on the Princes Highway detailed in section 3.4.5. As seen in Figure 6 the road surface had many large sharply edged stones sitting proud of the 7mm surface aggregate. These had the same affect as was discussed in section 3.4.4 where the test materials were point loaded causing premature failure (Table 18).

Table 18. Abrasion times for the C421 20/7/7 chip seal surface.

Test number → Fabric type	1 (s)	2 (s)	3 (s)	4 (s)	5 (s)	6 (s)	Mean (s)	St. Dev. (s)	CV% %
600D Polyester (P)	0.8	0.43	0.88	0.25	0.38	0.22	0.49	0.26	52.0%
500D Nylon (N1)	0.38	0.28	0.72	0.28	0.67	0.43	0.46	0.18	38.0%
1600D Nylon (N2)	0.43	0.17	0.28	0.33	0.59	0.28	0.35	0.13	38.4%
Leather	0.17	0.43	1.86	0.9	1.25	0.51	0.85	0.57	66.6%
Protective Denim	0.38	0.17	0.74	0.95	0.15	0.93	0.55	0.34	60.6%
Standard Fabric	1.16	0.88	0.95	0.72	0.51	1.39	0.94	0.29	30.5%

Both 20/7/7mm chip seal surfaces were highly abrasive to the materials tested (Figure 13). All material types only had a small number of samples that did not burst open on impact with both surfaces. The number bursting on impact increased to a point to where the coefficient of variation started to reduce. This was accompanied by a reduction in the mean time to hole as performance on all of the test samples was poor.

The results of these tests would suggest that 20/7/7mm multi aggregate chip seal surfaces displayed increased failure risks to all types of motorcycle clothing that would most likely result in an increased injury risks to motorcyclists in the advent of a crash. The failure mechanism was the same as for 20/7mm dual aggregate roads. As discussed in part 3.4.6 these surfaces should be avoided on high use motorcycle roads unless no other alternative is available.

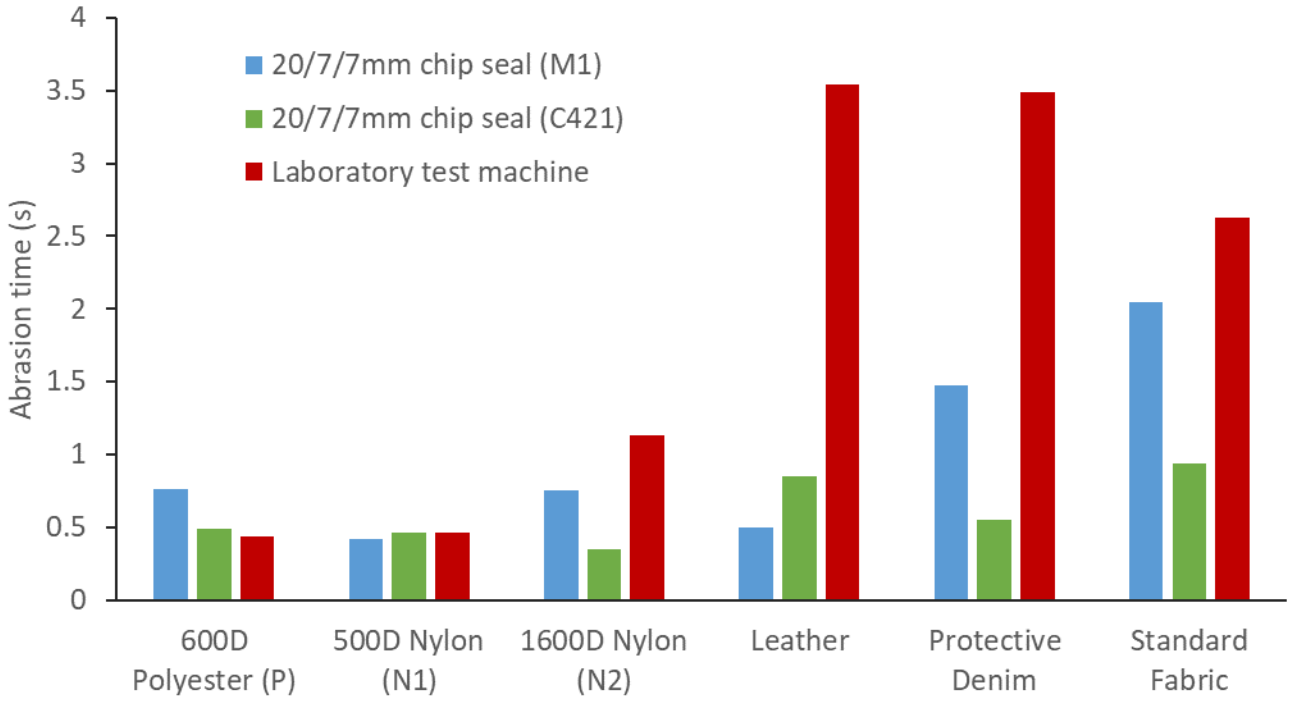


Figure 13. Abrasion performance of the different material combinations on 20/7/7mm chip seal surfaces and the laboratory test machine.

3.5 Mechanism of failure

The proposed models of interaction of a garment with a road chip seal surface are given in Figure 14. The present two proposed key elements influencing abrasion is the pressure distribution (closed arrowhead) and fibre catch points (open arrowhead). For a chip seal surface where the aggregate is flat (plate like in shape) it should produce a relatively flat surface after rolling (Figure 14a and b). The change in aggregate size should not have a significant effect on abrasion time as the pressure distribution should be similar over the flat surface and would only be changed if significant microstructure was present to provide hooks in the aggregate surface. The aggregate will have some fibre catch points caused by fracture edges from crushing however the force on these will be relatively low due to the distribution of rider body load over the remainder of the abrasion surface.

When the aggregate is changed to be more cubical in shape the abrasion damage of the road increases. This is due to less area distribution of the rider's body load increasing the force applied to the fibre catch points on the upper surface of the aggregate (Figure 14c). This will be significantly higher for aggregate that has a sharp fracture edge that provides upward facing points that act as fibre catch points. This increased abrasion damage will be further increased by increasing aggregate size as it will increase the gaps between aggregate points enabling further penetration into the protective clothing material structure and increasing the rider body load at each of these points.

Where two different aggregate sizes have been used to form the chip seal the macrostructure increases. The increase is dependant on the size difference between the aggregates and the shape of the two aggregates. In the example shown in Figure 14d the large difference results in a small number of contact points between the road and the riders clothing. The force at these points is significantly increased and can enable point cutting of the clothing materials. The point of the aggregate can snag the fabric and tear a hole in it. This is what was seen in Figure 11b and 11c where there is a flap of material present on the downstream side of the aggregate impact point. This mechanism of failure was seen in the 20/7 and 20/7/7 chip seal surfaces in this report. This type of failure holes the rider's garment in the first few milliseconds of contact with the road rendering them vulnerable to soft tissue injuries.

On a chip seal surface, the mechanism of clothing failure is predominately from removal of fibres from its structure. A hook is pushed into the material surface snagging a fibre and pulling on it. The fibre is then either broken at the point of snagging, partially drawn out forming a pile or pulled totally from the material. Sometimes the last mechanism requires further fibre breakage to allow the fibre to be released from the material structure. The presence and number of hooks is relevant to the macro and possibly microstructure of the aggregate as well as its shape. Macrostructure cannot be considered alone as a road made from unbroken polished river pebbles will have significant macrostructure but no hook points to drag fibres from the material surface.

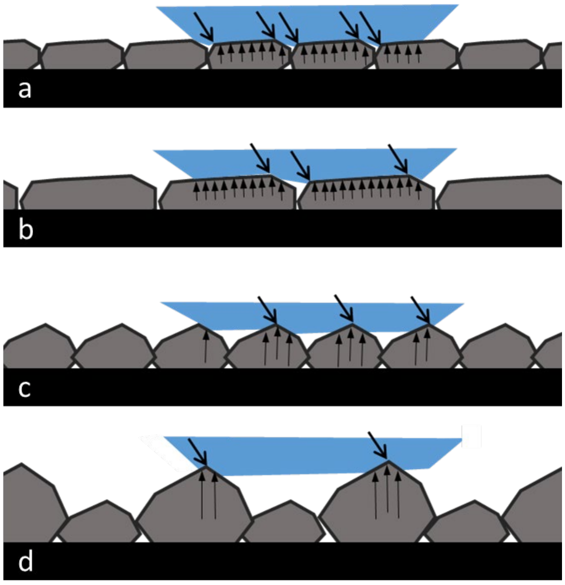


Figure 14. Models of protective clothing interaction with different road surfaces of (a) small flat aggregate chips, (b) large flat aggregate chips, (c) small cubical agregates and (d) dual cubical aggregate seal where there is a large difference in the size of the two aggregates.

On an asphalt surface fibre is still removed from the textile structure however the negative texture provides less hook points for this to occur. The negative texture also provides a relatively even surface for the increased distribution of pressure of the riders body reducing the abrasion damage (Figure 15). The materials are more likely to undergo fibre surface damage resulting in fibre fragments being removed rather than entire fibres. The increased length of abrasion results in an increase in the heat generated in the protective material from friction with the road surface. Protective materials that are made from thermoplastic polymers can be heated up resulting in strength loss or premature failure. Temperatures generated in this work have been high enough to melt textile fibres such as nylon, polyester and ultra-high molecular weight polyethylene (UHMWPE).

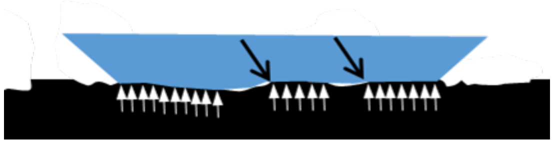


Figure 15. Model of protective clothing interaction with an asphalt road surface.

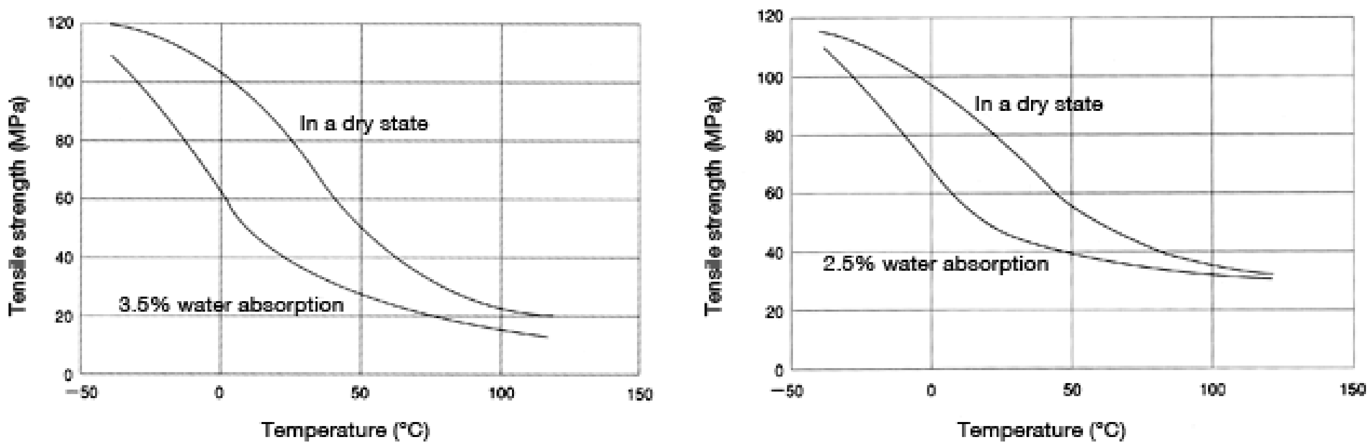
Heat is generated by friction and requires higher sliding times/distances before it becomes an issue for rider or clothing. An example of friction generated heat melting a polymer is for the 1600D woven nylon fabric tested in this work (Tables 3 and 4). Lumps of plastic were evident at the downstream end of the abrasion samples after testing when abrasion times were 2-3 seconds. Plastic beads were not present in the 500D nylon that lasted 1-1.5 seconds of sliding distance as holing formed before enough heat could be generated to melt the polymer. For the 1600D nylon this would equate to 16-24 meters of sliding distance before melting occurred. For crashes at lower speeds (<50km/hr) in an urban environment 16-24 meters should see the rider protected. For crashes at higher speeds on asphalt covered motorways and highways then this could cause an issue.

To melt a thermoplastic the heat generated from friction needs to exceed its melting temperature. Two nylons are used in protective textiles: nylon 6 and nylon 66. Nylon 6 has a melting temperature of 220°C and lower mechanical properties than nylon 66. Nylon 66 is commonly marketed under the name Cordura and has a melting point of 265°C. Both fibre types are used in motorcycle clothing. In this research both the 500D and 1600D nylon fabrics were nylon 6. The formation of beads after abrasion indicates that abrasion temperatures were getting to at least 220°C. These temperatures are well over the 160°C melting temperature of UHMWPE. This heat could be transmitted into the rider's body at the end of a slide either through materials that have not holed or from molten abrasion debris at the edges of the abrasion hole.

The heat generated from friction also needs to be able to transfer through the clothing layers and build up in the remaining protective material layer/s. Textiles and leather are natural insulators with low thermal conductivities (nylon 6 & 66=0.25 W/m.K, Leather=0.14 W/m.K and polyester 0.15-0.4 W/m.K) when compared to metal (aluminium=235 W/m.K and copper=400W/m.K). The thermal conductivity of textile materials is increased with the compression of the fabric between the body and the road but is still low. Thermal transfer can continue through the clothing layers even after the abrasion has stopped. A high temperature may be generated at the abrasion interface, and this can take several seconds to transfer through the material layer to the rider's skin.

Time is required to conduct the heat through the structure. The time of abrasion must be long enough to allow the heat to be generated and transferred within the materials. Thermal damage was not evident in samples that have undergone abrasion on chip seal. This may be due to the heated fibres being removed from the material structure before they can impart too much heat into remaining structure.

Although reaching the melting temperature is a point of critical failure the tensile properties of thermoplastic polymers such as nylon reduce as temperature increases (Figure 16). This could result in a tensile failure of the fabric before it reaches its melting temperature. Further work is required to determine what are the temperatures generated during abrasion and can these pose risks to the rider or their gear.



(a) (b)

Figure 16. Tensile properties of (a) nylon 6 and (b) nylon 66 at different temperatures (Toray Industries, 2019).

The calibration fabric can be used as a constant to determine if there is a relationship between the road surface and abrasion time (Figure 17). The two longer abrasion resistant materials (Protective Denim and Leather) show a strong correlation between road surface and abrasion time when they are plotted versus the calibration fabric abrasion time. The thinner fabrics have a weaker relationship which is due to the damage that they receive hitting the ground reducing the overall abrasion resistance of the fabric. This causes the fabric to fail over a wider spread of abrasion times giving the weaker relationship. The partial damage to the materials also results in a change to the slope of the relationship line. As the material lowers in abrasion resistance the line gets closer to vertical.

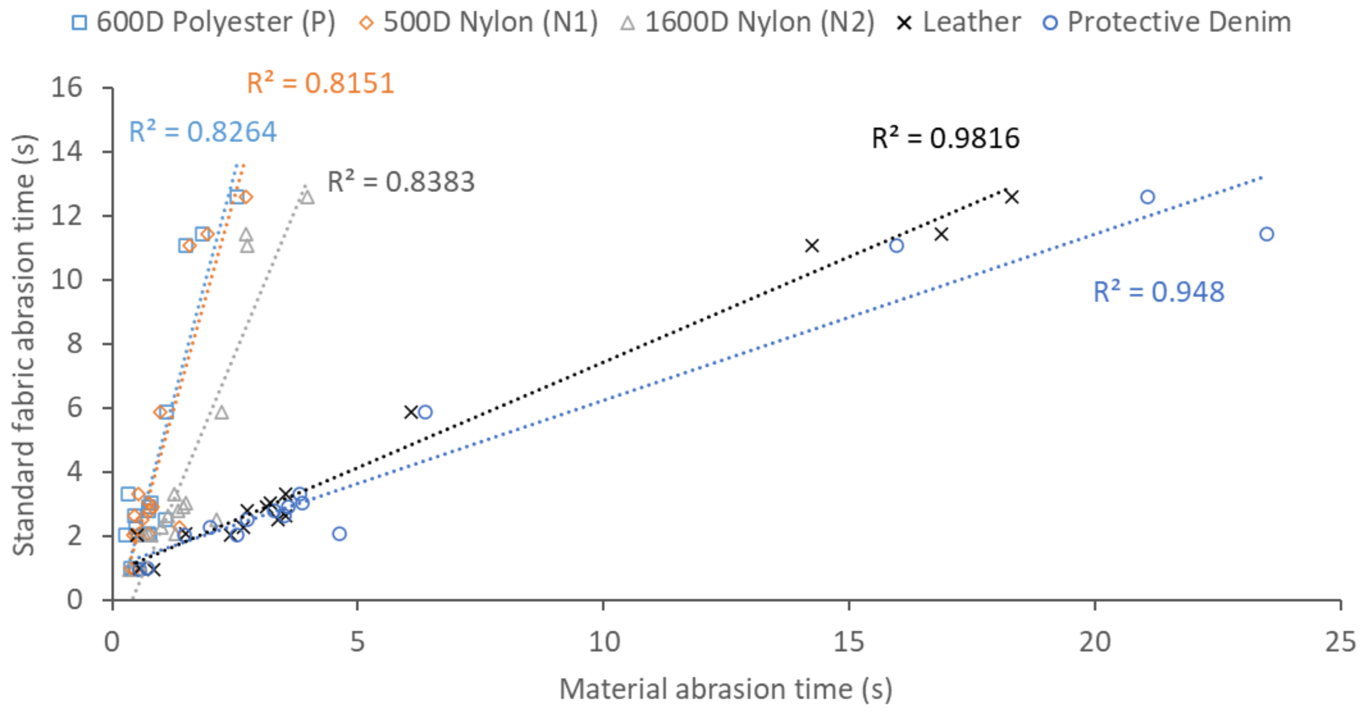


Figure 17. Material abrasion time relationship to calibration fabric time for all road surfaces.

The calibration fabric versus abrasion time plot indicates that there is a relationship between two different samples on different road surfaces. This is useful in the development of the laboratory test method as the abrasion time of the calibration fabric can be varied by using different abrasion grit belts. Previous work has shown that a 120 grit belt used on a laboratory Cambridge impact abrasion test machine had an abrasion time for the calibration fabric of 7.5-8 seconds. This is closer to the times achieved for asphalt which were 11-12.5 seconds. The grit of the abrasion tester could be varied to achieve calibration fabric abrasion times similar to those achieved on-road.

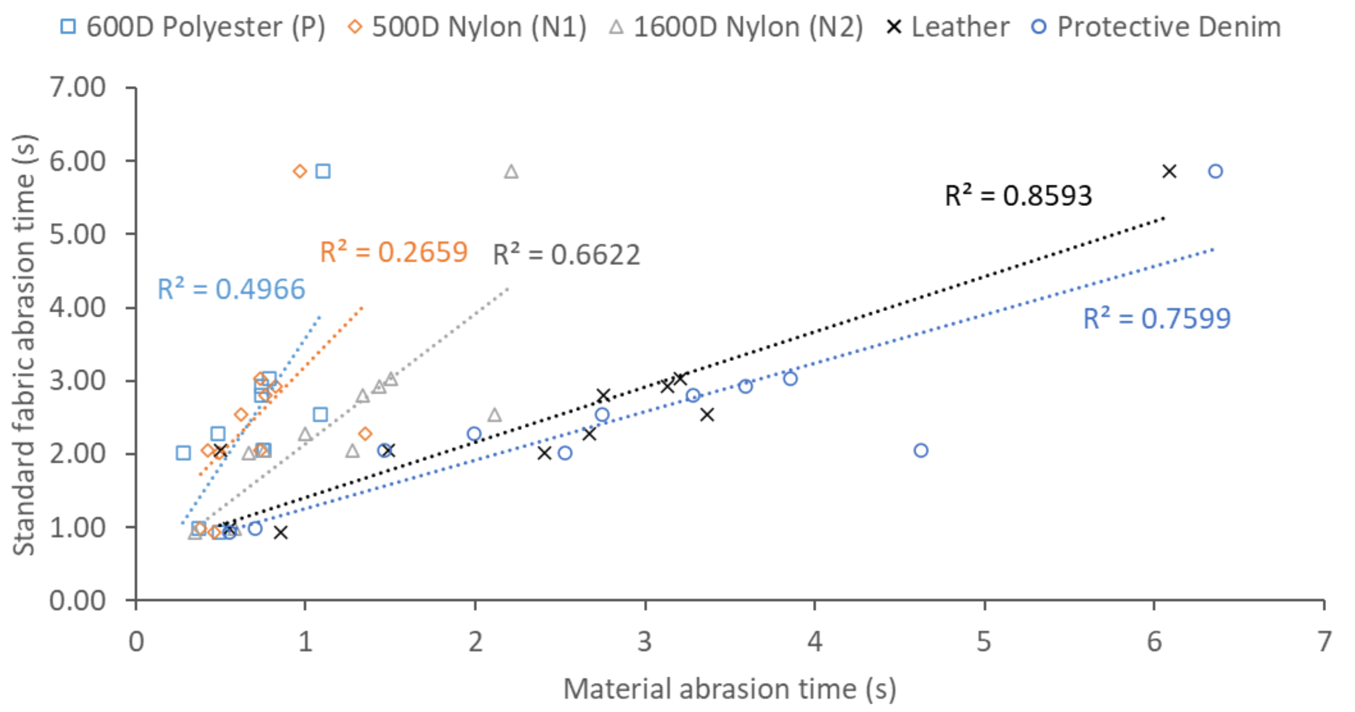


Figure 18. Material abrasion time relationship to calibration fabric time for all chip seal surfaces.

The R^2 values calculated in figure 17 may be artificially inflated due to the separate grouping of the asphalt and chip seal results. To determine if this was the case the chip seal results were plotted on their own (Figure 18). The R^2 values for the denim and leather are not as strong as they were for all samples however, they still are relatively strong. The protective textile R^2 values are significantly lower, which was expected as the sharp points and variability with chip seal surfaces are more likely to cause premature failure of test samples increasing the variability in measurements. Some fabrics would be more prone to point cutting than others hence how the thicker 1600D fabric had a higher R^2 value than the two thinner fabrics.

4 Conclusions and recommendations

This work has shown that asphalt surfaces on average are four and a half times less abrasive than chip seal surfaces. Commonly used chip seal surfaces have similar time to hole results as the laboratory Cambridge impact abrasion test machine. Chip seal surfaces made from cubical shaped aggregate were more likely to damage clothing than surfaces made from an equivalent flat shaped aggregate. Multi aggregate surfaces such as 20/7 were more likely to catastrophically damage motorcycle clothing due to the three-dimensional surface created by the difference in aggregate size. Damage in these surfaces was from cutting and tearing of the protective clothing materials by the larger aggregate protruding from the surface during initial impact with the road surface.

The findings from this work show that it is suitable to use the laboratory Cambridge impact abrasion tester for estimation of clothing protection levels for MotoCAP. They also show that a dual level message should be used with urban environments differentiated from rural environments. The recommended message is "Two star or better clothing for urban riding and three star or better for rural riding".

It is recommended that the following future work is conducted to further expand the knowledge in this space.

- Testing on more asphalt surfaces to ensure there are not outliers within the road group.
- Testing in different weather conditions with an emphasis on temperature and humidity to determine how much they effect protection.
- Asphalt and chip seal testing to determine the heat of friction generated in samples and if this can pose a risk of burns to the rider or melting to the clothing materials.
- Testing on targeted chip seal surfaces to determine the influence of microstructure on abrasion damage.

5 Limitations

The control of road temperatures and moisture levels was unavailable during testing. The effect of temperatures on the abrasion time, need to be investigated.

Test samples were only tested on the road in the zero-degree orientation due to time limitations and to ensure statistical significance from the results wherein normal testing looks at testing at three different test angle to fully appreciate the abrasion differences.

For a better understanding of the effect of asphalt macrostructures on the abrasion time of protective textiles, more asphalts road surfaces need to be tested.

6 Test locations

Images and a description of each of the test locations is given below.

The section of Nicol Drive South used for testing is a new feeder road up to the solar array at the rear of the university grounds. The asphalt surface had been laid six months prior to testing but had seen moderate levels of traffic from heavy equipment accessing the solar array. Images of the test location are shown in figure 19.

Figure 19. Images showing the asphalt test surface layout at Nicol Drive South including the traffic control, test rig mounting and test sample change.

This research tested four road surface types on the Princes Hwy East of Colac. The four different surface types including: 20/7/7mm chip seal, 20/7mm chip seal, 10mm C170 geotextile topped with a 14/7 chip seal cover and a 14/7mm chip seal.

These road surfaces were adjacent to each other and some images of running the test steps are shown in Figure 20.

(a) (b) (c)

Figure 20. (a)Road closure service provided by the traffic control team, (b) the impact abrasion test rig mounted to the tow vehicle, (c) assembling fabric on the test head of the impact abrasion tester.

Note: The images were taken in East bound of slow lane Princess Hwy, near no 6190.

Five rural road locations were used for this study. All the road surfaces were flat and clean over the full length of the test. The images of some of these roads are shown in Figure 21 and 22.

Figure 21. Road closure service provided by the traffic control team in rural road locations. The images are taken in Wancoort-Birregura (left) and Birregura Rd (right) locations.

Figure 22. Images of the test location at Gellibrand showing the test surface and the test head.

References

Albanese, B., Gibson, T., Whyte, T., Meredith, L., Savino, G., De Rome, L., . . . Brown, J. (2017). Energy attenuation performance of impact protection worn by motorcyclists in real world crashes. *Traffic Injury Prevention*, 00-00. doi: 10.1080/15389588.2017.1311014

Austroads. (2000). *Guide to the selection of road surfacings Austroads Publication No. AP-63/00,* Sydney, Australia: Austroads.

CEN. (2002a). Protective clothing for professional motorcycle riders - Jackets, trousers and one-piece or divided suits *Part 2: Test method for determination of impact abrasion resistance* (Vol. EN 13595-2:2002, pp. 1-12). Brussels: European Commitee for Standardisation

CEN. (2002b). Protective clothing for professional motorcycle riders: Jackets, trousers and one piece or divided suits - General requirements *EN 13595-1:2002*: European Committee for Standardisation, Brussels.

CEN. (2015). Protective gloves for motorcycle riders – Requirements and test methods (Vol. EN13594:2015, pp. 1-29). Brussels: European Commitee for Standardisation

CEN. (2020). Protective garments for motorcycle riders - Part 1: Test methods (Vol. EN17092-1:2020). Brussels: European Commitee for Standardisation

Cortili, G., Mognoni, P., & Saibene, F. (1996). Work tolerance and physiological responses to thermal environment wearing protective NBC clothing. *Ergonomics, 39*(4), 620-633.

Darmstadt, T. U. (2018). Darmstadt method determining the abrasion resistance of motorcycle protective clothing. Retrieved 30/03/2020, 2020, from https://www.fzd.tu-darmstadt.de/fzd/equipment_fzd/test_benches_fzd/aart/index.en.jsp

de Rome, L. (2018). Stars or standards? A review of motorcycle protective clothing from the southern hemisphere. https://www.racfoundation.org/research/safety/stars-or-standards-a-review-of-motorcycle-protective-clothing. London, UK: RAC Foundation

de Rome, L., Ivers, R., Fitzharris, M., Du, W., Richardson, D., Haworth, N., & Heritier, S. (2011). Motorcycle protective clothing: Protection from injury or just the weather? *Accident Analysis and Prevention, 43*(6), 1893-1900. doi: DOI: 10.1016/j.aap.2011.04.027

de Rome, L., Ivers, R., Fitzharris, M., Haworth, N., Heritier, S., & Richardson, D. (2012). Effectiveness of motorcycle protective clothing: Riders' health outcomes in the six months following a crash. *Injury: International Journal of the Care of the Injured, 43*, 2035-2045. doi: DOI:10.1016/j.injury.2011.10.025

de Rome, L., Meredith, L., Ivers, R., & Brown, J. (2014). Validation of the principles of injury risk zones for motorcycle protective clothing. DOI: 10.1016/j.jsr. *Journal of Safety Research, 50*, 83-87. doi: DOI: 10.1016/j.jsr.

Meredith, L., Hurren, C. J., Clarke, E., Fitzharris, M., Baldock, M., de Rome, L., . . . Brown, J. (2016). *Abrasion Resistance Performance of Clothing Worn by Australian Motorcyclists.* Paper presented at the IRCOBI Conference 2016*,* Malaga, Spain.

Meredith, L., Hurren, C. J., Clarke, E., Fitzharris, M., Baldock, M., de Rome, L., . . . Brown, J. (2017). Validation of the abrasion resistance test protocols and performance criteria of EN13595: The probability of soft tissue injury to motorcycle riders by abrasion resistance of their clothing. *Journal of Safety Research, 61*(June), 1-7.

Nunneley, S. A. (1989). Heat stress in protective clothing. Interactions among physical and physiological factors. *Scandinavian Journal of Work, Environment & Health, 15*(SUPPL. 1), 52-57.

NZ, T., RCA, & NZ, R. (2005). *Chipsealing in New Zealand*. Wellington, New Zealand.: Transit New Zealand, Road Controlling Authorities, Roading New Zealand.

Schuller, E., Beir, G., & Spann, W. (1986). Disability and impairment of protected and unprotected motorcycle riders. *SAE Technical Papers*.

Toray Industries, I. (2019). AMILAN™ Nylon Resin - Technical Information | Properties | Mechanical properties. Retrieved 22/09/2021, from https://www.toray.jp/plastics/en/amilan/technical/tec_001.html

Woods, R. I. (1996a). Belt abrader impact abrasion testing of leathers and fabrics used in motorcycle riders' clothing. In J. S. Johnson & S. Z. Mansdorf (Eds.), *Performance of Protective Clothing* (Vol. Fifth Volume, pp. 57-69). Philadelphia: American Society for Testing and Materials.

Woods, R. I. (1996b). Specification of motorcyclists' protective clothing designed to reduce road surface impact injuries. In J. S. Johnson & S. Z. Mansdorf (Eds.), *Performance of Protective Clothing* (Vol. Fifth Volume, pp. 3-22). Philadelphia: American Society for Testing and Materials.

Woods, R. I. (1996c). Testing of protective clothing for Motorcyclists: Validation of laboratory tests by accident studies. In J. S. Johnson & S. Z. Mansdorf (Eds.), *Performance of Protective clothing* (Vol. Fifth Volume, pp. 43-56). Philadelphia: American Society for Testing and Materials.

Zettas, J., Zettas, P., & Thanasophon, B. (1979). Injury patterns in motorcycle accidents. *Journal of Trauma - Injury, Infection & Critical Care, 19*(11), 833-836.