A guide to designing and manufacturing motorcycle protective clothing

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About this guide

Evidence from motorcycle crash studies and laboratory reports reveals that many of the personal protective equipment (PPE) garments currently available for motorcycle riders fail to protect the wearer, even in relatively low-speed crashes. The difference between effective and ineffective motorcycle PPE does not have to be expensive; it can be simply a matter of design and technique.

This guide aims to increase the effectiveness of motorcycle protective jackets and pants by providing manufacturers with scientifically based information that will help them determine the best materials and methods for constructing more effective PPE.

The overall objective is to increase motorcyclists' access to protective clothing that is effective, and that is suited to their riding conditions and climate.

Who is this guide for?

This guide assumes that readers are experienced in the manufacture of motorcycle protective clothing, and familiar with the range of materials and processes used. The contents are based on current industry practice and standards, together with new information from research into ways to increase the effectiveness of these products under all riding conditions.

The focus of this guide is on jackets and pants for riding on public roads for work or leisure. The information is also relevant for the design and construction of two-piece and one-piece suits.

The challenge of designing motorcycle clothing

Unlike most occupational PPE, motorcycle clothing serves a number of functions.

- It provides protection from:
    - injury in a crash due to impact with road surfaces
    - other road users who may fail to see and give way to the rider
    - the weather, including windy, hot, cold and wet conditions.
- It can be appropriate or readily modifiable for wear at the rider's destination.

The challenge for manufacturers is to meet all these functions without restricting the rider's ease of movement, or causing discomfort, fatigue or physiological stress. The process of designing and manufacturing these garments involves successive stages, with testing to ensure products will work as required. Figure A illustrates the design and development process, including stages when key design decisions are tested before proceeding further.

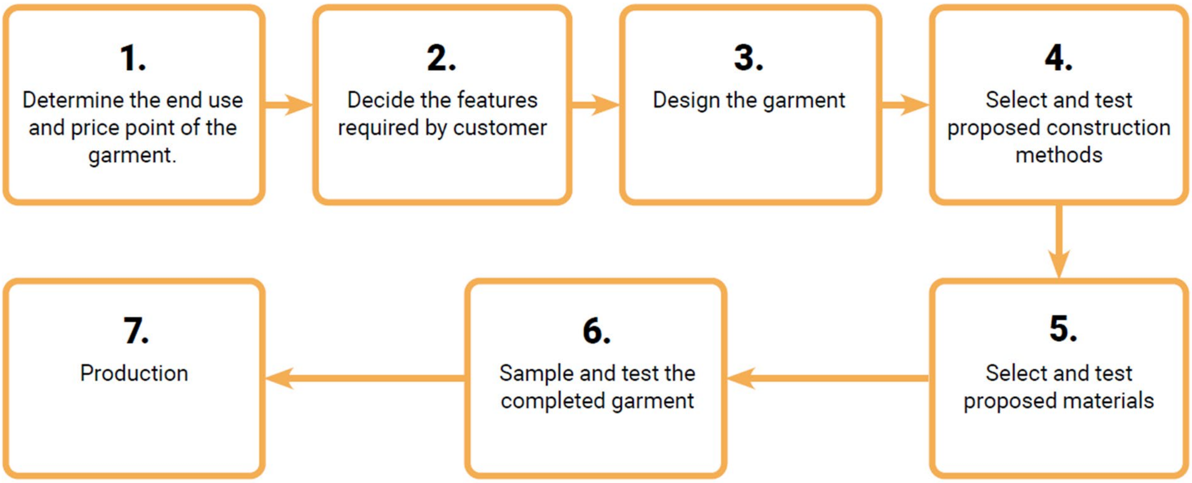


Figure A: Stages in the design and development process for motorcycle protective clothing.

Testing results

A key feature of this guide is a series of tables (see Appendices A, B and C) that report the results of tests on the most commonly used materials and construction methods for motorcycle PPE. These results cover abrasion resistance, burst and tensile strength, and breathability. As most new and small manufacturers do not have ready or affordable access to test facilities, this information will enable manufacturers to make informed decisions without the expense of commercial testing.

1 Introduction

This chapter includes the following sections:

1.1 A summary of research into the injuries to motorcycle riders.

1.2 Design features, such as breathable materials and ventilation, that can reduce the potential crash risks due to discomfort.

1.3 The evolution and current status of industry standards for motorcycle PPE.

1.4 The MotoCAP consumer rating scheme and how it can benefit industry.

1.5 Emerging materials, technology and sustainability issues relevant to motorcycle protective clothing.

1.1 Crash and injury risks for motorcyclists

The majority of riders who crash are injured but not killed, and the majority of those injured are not hospitalised. Those wearing motorcycle protective clothing are less likely to have any injuries – unless their clothing fails. The evidence suggests that the vast majority of all those who crash would benefit from the availability of well-designed motorcycle PPE.

Figure 1.1 illustrates the crash and injury rates in Australia over the past decade. On average, 218 motorcyclists died in road crashes each year between 2008 and 2017, while 8,062 were hospitalised and 24,185 were injured but not hospitalised. Figure 1.1 compares annual Australian motorcycle fatal and injury crash rates per 10,000 registered motorcycles over ten years.

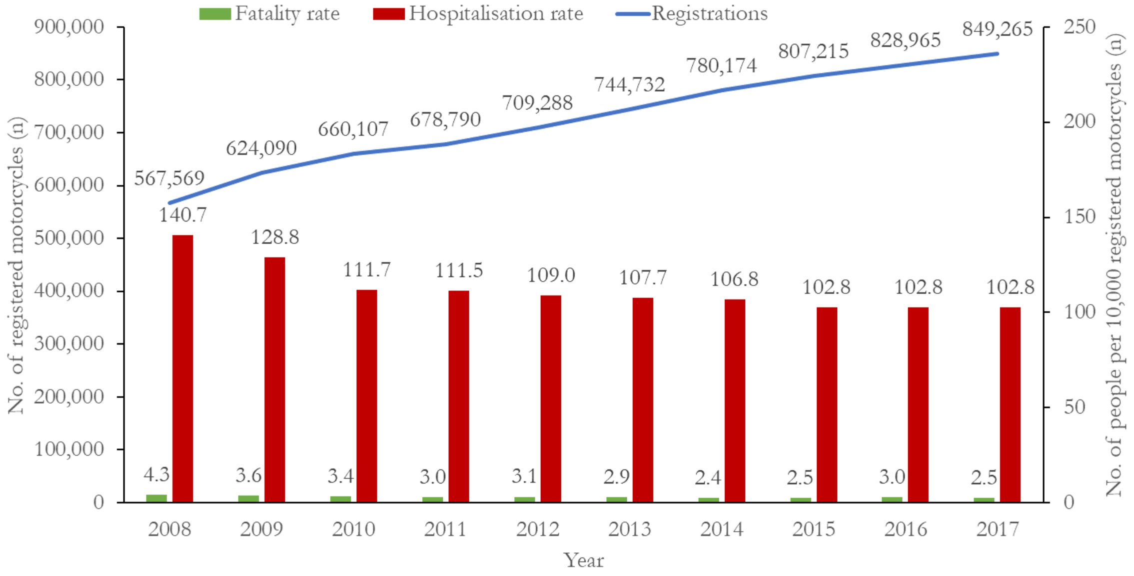


Figure 1.1: Motorcycle fatality and hospitalisation crash rates per 10,000 registered motorcycles, Australia.

Table 1.1 shows the distribution of injury types and locations from a population-based study of all injury claims for motorcycle on-road crashes in the state of Tasmania over five years (2012–2016). This table includes the number of claims relating to injuries by body region, and the types of injury within each body region.

Table 1.1: Motorcyclist injury types and injury locations, Tasmania, 2012–16.

		All claims	Fractures	Open wounds	Soft tissue	Bruises	Internal organ	Other injuries
Body region	**n**	**Col %**			**Row %**			
Head/face	272	15	11	25	–	8.1	53	17
Spine/neck	365	20	25	–	76	–	–	–
Upper torso	352	19	51	8.5	12	27	20	8
Arm/shoulder	773	43	35	21	40	16	–	6
Hand/wrist	480	27	51	22	25	6	–	10
Lower torso	296	16	17	27	1.4	40	0.7	22
Leg/knee	807	45	22	41	30	25	–	5.8
Foot/ankle	363	20	42	5	39	9.4	–	20
Row %	**–**	**100**	**50**	**30**	**46**	**25**	**12**	**17**
All claims (n)	**1806**	**1806**	**911**	**550**	**827**	**445**	**210**	**308**

The first three columns show the number and proportion of claims for injuries to each part of the body, as relates to the protective equipment that could be worn. Almost half of all claims included leg injuries (45%) and/or arm/shoulder injuries (43%), with fewer claims for injuries to the hand/wrist (27%) and foot/ankle (20%). Row percentages show types of injury sustained by each body area. More than 50% of head injuries involved internal organs (brain), but a quarter had open-wound injuries, which were mostly (70%) to the face.

Half of all claims involved fractures (50%). Soft-tissue injuries (46%) were the next most frequent, followed by open wounds (30%), bruises (25%), internal injuries (12%), and other injuries (17%) where insufficient details were provided.

Comparing the prevalence of injury types between body regions, the hand/wrists (51%) and upper torso (51%) sustained the highest proportion of fractures, followed by foot/ankle (42%) and arm/shoulder (35%). Open wounds (41%) were the most frequent injury to the legs, and just 22% of leg injuries were fractures – compared to 30% soft-tissue injuries and 25% bruises to that region.

The head was the body region least frequently injured, comprising 15% (n=272) of all cases, but including the highest proportion (53%) of internal injuries. The majority of fractures, open wound and bruise injuries were to the face and jaw. It should be noted that helmet usage is mandatory in Tasmania and all Australian states, with national usage rates close to 100%.

Spinal injuries were reported by 20% of claimants (n=365) of whom 25% (n=92) had spinal fractures and 76% had soft-tissue injuries (n=279). The thoracic spine accounted for 41% of spinal fractures, compared to 29% cervical spine and 27% lumbar spine. The cervical spine also accounted for 51% of soft-tissue injuries, with less than 1% each for the thoracic and lumbar spine regions. The specific sites of other soft-tissue spinal injuries (n=160) were not specified in the medical reports.

The upper torso, excluding the spine, accounted for 19% of all claims and 20% of internal injuries. Ribs accounted for 51% of all injuries and 95% of all fractures to the upper torso.

1.2 The importance of rider comfort/ergonomics

Despite the established benefits of motorcycle PPE, many riders continue to ride unprotected, and heat discomfort has been identified as a key disincentive. Riders who own but do not always wear PPE have reported being three times less likely to wear it in hot conditions due to thermal discomfort.

The PPE required in many occupations is often hot and uncomfortable due to the highly insulating materials used. However, occupational PPE is worn only for the duration of exposure to imminent hazards. This is not the case for motorcycling, which is a form of transport rather than an inherently hazardous occupation.

Under normal conditions, the body maintains a stable core body temperature by expelling excess metabolic heat through sweating. Provided the sweat evaporates, more sweat can be expelled until the core temperature is regained. When sweat cannot evaporate, because the skin or adjacent clothing has become saturated, the wet surface will prevent the expulsion of more sweat. The excess body heat becomes trapped within the body, causing the core temperature to rise, and leading to heat discomfort and potentially heat strain (hyperthermia).

Hyperthermia is not a trivial issue but a physiological condition that can become a serious health risk, even with relatively small increases in core body temperature. It occurs when the body's core temperature increases above 37.5°C, with potentially severe consequences for physiological and cognitive function. At these temperatures, individuals may experience heat exhaustion, with fainting, cramps or confusion, and difficulty concentrating. The most serious stage occurs if the body's core temperature reaches above 40°C, which can result in heatstroke, organ failure and death.

Laboratory studies have measured the physiological impact of wearing non-breathable motorcycle garments at ambient temperature (23°C). They found that sweat production was doubled when wearing non-breathable garments compared to breathable garments, and heart rates, skin and core temperatures all increased within 30 minutes. When the temperature was raised (35°C), the severity of those physiological responses increased, compounding rider discomfort and impairing reaction times, fatigue and mood, with implications for riding safety.

The risks of heat strain can occur in all climates and temperatures when garments are not sufficiently breathable or ventilated to allow sweat to evaporate. Excessive sweating is an indicator that the body is struggling to maintain a normal temperature. In a healthy person, this may be due to excessive heat input from external heat sources or when high humidity prevents sweat from evaporating.

Tests of the vapour permeability of a wide range of motorcycle jackets and pants have confirmed that most could impose significant thermal strain under average Australian summer conditions. Research conducted with riders wearing motorcycle garments with low vapour permeability, under average Australian summer conditions (35°C and 40% humidity), found their core temperatures increased by 2°C, skin temperatures by 3°C and heart rates by 66bpm, over a 90-minute trial. Tests of cognitive function during the trial also observed increased fatigue, mood dysfunction and impaired reaction times.

The primary functions of motorcycle clothing are to ease the demands of riding. While protection from injury is the essential function of motorcycle clothing, equally important is ensuring it is not a source of discomfort or distraction, which may increase the risk of a crash. Breathable garments must be designed to draw sweat moisture away from the rider's body, allowing the sweat to evaporate, while preventing external water vapour from passing through the garment to increase the moisture load on the skin. Ventilation ports and mesh/perforated panels may provide sufficient ventilation in dry conditions but are not effective in wet conditions.

1.3 Standards for motorcycle PPE

1.3.1 The EU Personal Protective Equipment Regulation

The European Parliament's Personal Protective Equipment Regulation 2016/425 came into force on 21 April 2018. This has significantly changed the motorcycle protective clothing space in Europe. The regulation requires that all clothing sold in the European Union must be certified according to the legislation, and a significant amount of clothing in the worldwide motorcycle clothing market has now been certified. It is important for manufacturers looking to sell products in Europe or the United Kingdom (where, following the UK's exit from the European Union, a separate certification system known as UKCA has been implemented) to be familiar with the applicable standards and ensure their clothing is certified before supplying to the market.

1.3.2 The Cambridge Standard

The Cambridge Standard, developed by Dr Roderick Woods at Cambridge University in 1994, was the first published standard for motorcycle protective jackets and pants. The Standard is based on four levels of impact risk that were identified by mapping the distribution of crashed riders' injuries and clothing damage. Under this system, Zone 1 had the highest risk exposure and required protection from impact forces and abrasion damage; Zone 2 also had the highest exposure to abrasion but did not require impact protection; and Zones 3 and 4 had decreasing levels of abrasion risk and little impact risk, respectively.

1.3.3 Standards for impact protection

In 1998, the European Standards body – the European Committee for Standardization, known as CEN – published EN 1621-1:1998 for motorcyclists' protective clothing against mechanical impact. Applying Wood's four impact-risk zones, the European Standard required impact protectors to be in Zone 1 with the average maximum force transmission not to exceed 35kN. At the time of writing, the latest edition of this Standard is EN 1621:1:2012.

Additional elements have subsequently been added to the impact standard. These enable the measurement of motorcyclists' back protectors (EN 1621-2:2014), chest protectors (EN 1621-3:2018) and inflatable protectors (EN 1621-4:2013). A further standard for electronically activated inflatable protectors was under preparation at the time of writing. All use the same testing equipment with variation in impact energy and impactor mandrel geometry. Compliance with the standards has been strong and has seen the development of protectors that are differentiated according to protection levels, thinness and flexibility.

1.3.4 European standards for motorcycle riders' jackets and pants

The Cambridge Standard became a model for the development of the European Standard EN 13595:2002 for jackets, pants and one- or two-piece suits for professional riders. While compliance was mandatory within Europe, it was not enforced, and the Standard was largely ignored by both the industry and the rider community.

In 2012, the French Government introduced a modified version of EN 13595 for "non-professional riders", called the French Protocol (NF EN 13595), which reduced the requirements for abrasion, cut and tear resistance.

In 2020, the European Union released a new standard for motorcycle jackets and pants (EN 17092:2020). The new standard was supported by accompanying regulations making compliance mandatory and enforceable for manufacturers. It came into effect in April 2018.

EN 17092:2020 applies specifically to on-road riding and has five levels of protection. It does not include the distinction between professional and non-professional (recreational) use, which was present in EN 13595. The main differences between EN 13595 and EN 17092 are the way in which abrasion resistance is tested, and the reduction from four to three impact risk zones.

A comparison of the two European standards and the MotoCAP program is given in Table 1.2. The European standards are further described below.

Table 1.2 Comparison of testing schemes and standards.

Scheme	Risk zones	Abrasion	Seam strength	Cut	Impact	Tear	Thermal
EN 13595	4-zone system	Cambridge	Hydraulic burst	Impact cut	EN 1621	ISO 4674:2016 ISO 3377:2011	Not assessed
EN 17092	3-zone system	Darmstadt	Tensile strength	Not assessed	EN 1621	ISO 4674:2016 ISO 3377:2011	Not assessed
MotoCAP	4-zone system	Cambridge	Hydraulic burst	Not assessed	EN 1621	Not assessed	Thermal sweating hotplate

EN 13595

EN 13595:2002 closely followed the test methods detailed in the Cambridge Standard and comprised measures of four key criteria: impact abrasion resistance; seams and fasteners burst strength; materials tear strength; and impact cut resistance. It was published in four parts:

- EN 13595-1:2002 covers the general requirements for a garment to meet one of two performance levels (Level 1 and Level 2).
- EN 13595-2:2002 details the impact abrasion test using the Cambridge (CAM) test machine.
- EN 13595-3:2002 details the method for undertaking burst resistance of seams and fasters using a Mullen type hydraulic burst tester.
- EN 13595-4:2002 details the method for determining impact cut resistance using a falling knife.

NF EN 13595 (French Protocol)

In 2012, the French Government introduced their revised version of EN 13595:2002, also known as the French Protocol. While still using the EN 13595:2002 test methods, the French Protocol reduced the abrasion, impact cut and tear resistance requirements for Zones 2 and 3. It also retained identical abrasion resistance requirements in Zone 1 for both performance levels (4.0s). The protocol changed the injury risk matrix to a three-zone system by combining Zones 2 and 3 and reassigning them to a moderate risk of abrasion. Garments certified to the French Protocol have two levels of protection that are often shown on garments using the French spelling for 'level', *Niveau*.

EN 17092

EN 17092 has five protection levels (AAA, AA, A, B and C). Classes AAA to A garments have the highest requirements for protection against all risks designated in the three-zone matrix, with Level A garments representing the lowest requirements.

In contrast, Class B and C garments have lower levels of protection required and do not offer protection against all the risk types identified in the three-zone matrix. Class B garments do not provide any impact protection; Class C garments only provide impact protection and are designed to be worn in combination with the other garments from the other Classes. Class C garments are also used in the off-road and motocross markets, where limb and upper-body impact protection is often provided by standalone garments.

The new standard is published in six parts. The first part, EN 17092-1:2020, details the methods for performing each of the tests, and provides details of the three-zone risk system. The remaining five parts correspond to five classes of protection (in descending order of test severity, EN 17092-2 to -6:2020: Classes AAA, AA, A, B and C respectively).

The method for testing impact abrasion resistance for EN 17092 was changed to the Darmstadt abrasion method (DAM). This machine is also referred to as an Advanced Abrasion Resistance Tester (AART). The DAM utilises a pass-fail criterion determined by the formation of a 5mm or greater hole. The test drops an undriven test sample onto a concrete abrasion surface at a set speed and allows it to slow to a stop under friction. Limited comparisons indicate that the DAM method is less aggressive than the CAM method: a 707rpm test speed pass on the DAM corresponds to a 1.4-second abrasion time on the CAM.

The method for assessing seam strength in EN 17092 was changed from the hydraulic burst test in EN 13539-3:2002 to the tensile method still used for motorcycle gloves (EN 13594:2015). The method applies a tensile load to a 25mm seam segment and measures the force per millimetre required to rupture the seam. This method is directly comparable with the hydraulic burst method detailed in EN 13595-3:2002, with correction factors available to convert between the two tests. See Section 2.6 for a direct comparison of the two seam-strength methods.

The process for having garments certified to the European Standard requires manufacturers to supply a completed garment in a single size as a reference, along with flat sheets of the materials and seams used in the construction of the garment. It is those sheets that are tested for abrasion, seam strength and tear resistance. Test houses certified to provide EN 17092 certification of clothing include SATRA in the UK, CTC Groupe in France, Ricotest in Italy, TUV in Germany and IDIADA in Spain, although the official European Commission database of certification bodies accredited to test and certify motorcyclists' clothing extends to a full list of more than 30 organisations.

1.4 Motorcycle Clothing Assessment Program (MotoCAP)

The Motorcycle Clothing Assessment Program (MotoCAP) is an independent program that buys, tests and rates motorcycle protective clothing purchased from Australian and New Zealand retail stores. Clothing is randomly selected and covertly purchased to ensure the independence of the program. The clothing is tested for three main protection components: impact abrasion, burst strength and impact protector energy attenuation. Garments are also tested for breathability, which is a measure of thermal comfort in a hot environment. Where relevant, water-resistant riding garments are tested for resistance to water spray. All results are provided free online at www.motocap.com.au and www.motocap.co.nz.

1.4.1 Development and aims

The MotoCAP protocol was developed by a group of research and industry experts, led by Deakin University on behalf of a consortium of government agencies and organisations from across Australia and New Zealand. The first batches of garment test results were released to the public in September 2018.

The aim of MotoCAP is to reduce the risk and severity of motorcycle crash injuries by increasing the availability of effective protective clothing and encouraging greater rider usage. The program:

- encourages the industry to increase the supply of effective protective clothing for all motorcycle riders
- enables riders to make well-informed decisions through independent, scientific information on the protective and thermal management performance of motorcycle protective jackets, pants and gloves
- creates an assured market for industry to invest in the production of garments that are protective and suitable for use in hot conditions
- provides independent test performance results to manufacturers to allow them to benchmark their products against others within the market
- provides a mechanism for manufacturers to differentiate themselves against their competitors in the protective performance of their products.

1.4.2 Testing methods

The methods used in the MotoCAP test protocols are based on European standards but are adapted to allow sampling from already constructed clothing:

- Impact abrasion is measured using a Cambridge-type impact abrasion testing machine following the method outlined in EN 13595-2:2002.
- Burst testing of seams and fasteners is measured using a hydraulic burst tester following EN 13595-3:2002, with a reduction in the diameter of the burst area to 79.9mm.
- Impact protector energy attenuation is measured using a twin wire drop-testing rig following EN 1621-1:2012.
- Breathability is measured using a thermal sweating hotplate following ISO 11092:2014 for both wet and dry measurements.
- MotoCAP glove testing follows EN 13594:2015 except for impact abrasion testing, for which it follows the older 2003 version of the standard that specified the same 60-grit abrasion belt as used in EN 13595-2:2002 for jackets and pants. Using the same grade of abrasion belt allows protection comparisons to be equal between the gloves, jackets and pants tested by MotoCAP.

1.5 Emerging materials and sustainability

Motorcycle protective clothing has gone through several iterations over the past 50 years. Early clothing was made from leather and heavy canvas fabrics. Synthetic materials became more dominant in the 1980s and ’90s, as wet-weather gear started to incorporate protective elements to make them multi-functional. High-strength fibres such as para-aramid and ultra-high-molecularweight polyethylene (UHMWPE) started to emerge in the late ’90s, as did protective denim jeans. Most recently, the industry has responded to demand for more casualised rider clothing such as riding shirts and hoodies, which can be worn by riders both on and off their motorcycles or scooters.

1.5.1 New materials

The acceptance of new and unfamiliar materials may be a challenge for the manufacturers of motorcycle clothing and their customers but will depend on effective marketing and the use of quantitative assessment schemes such as the European standards and MotoCAP. Independent assessment is important because protection is not always afforded simply by the type of fibre that a garment is made from. The structure and design of how the material is used is at least as important to effective performance as is the choice of fibre.

The structure of the fabric and the garment play an important part in resisting abrasion damage. Lower-performing fibres can replace the more expensive but better-performing fibres when the material or garment has the optimal structure. For example, double layers of a lighter shell material will provide substantially greater abrasion resistance than a single heavier layer of the same material.

Swapping to a different fibre type will need independent verification of abrasion resistance, together with targeted marketing to assure riders that the product is protective. This is especially important when well-known fibre types, such as cotton or regenerated cellulose, are used. Riders generally incorrectly assume that protection can only come from high-performance fibres, a result of marketing claims that use terms such as “ballistic nylon”, and advertising demonstrations of inappropriate test methods such as suspending cars from a pair of pants.

Well-informed marketing is especially important when well-known fibre types, such as cotton and regenerated cellulose, are used. An example is the knitted terry-loop protective liner fabric used by some manufacturers for abrasion resistance. One manufacturer uses para-aramid fibres within their protective liner, while another uses high-tenacity polyester fibre. Both perform at a similar level in protection, as it is the structure of the terry loop that makes it perform well in abrasion. Similar abrasion protection might be expected if the loop was constructed with a cotton or high-tenacity regenerated cellulose fibre. In addition, the cotton and regenerated cellulose would be lower in cost and higher in breathability than the synthetic fibres, providing significant benefit to the rider. However, it may be harder to sell this product as it goes against previous marketing language used by the industry.

1.5.2 Sustainability of materials

Sustainability is an emerging issue facing the motorcycle protective clothing industry. Two key factors have the potential to cause problems for the industry when trying to increase the sustainability of their products:

1. **The requirement that garments are constructed with minimal impact on the environment**. For animal welfare and environmental reasons, there is a growing movement to avoid the use of animal products in clothing. The items identified as being of issue include

leathers and animal fibres. The use of synthetic leather and sustainably sourced fibres can alleviate this issue.

2. **The concept of a Product Stewardship Scheme**. Product stewardship relates to requirements for manufacturers to accept their old used and discarded garments from wearers to be broken down into individual components for recycling. Product stewardship is designed to keep garments out of landfill and increase reuse of resources. The complexity of motorcycle garments makes their recycling complex.

If we use a pair of protective denim jeans as an example, the recycling and breakdown of this product would be difficult due to the number of materials used, and the garment's method of construction. In their current form, most protective denim jeans are made from multiple materials, including:

- cotton or polyester/cotton denim fabric
- polyester or nylon sewing thread
- para-aramid knitted protective liner fabric
- polyester mesh fabric comfort liner
- metal reinforcing studs and fly button
- polyester zipper
- polyester care tags and labels.

Disassembling a pair of protective denim jeans may therefore cost more than their manufacture unless careful thought is given to product design. The whole garment could not be recycled using traditional textile methods because of the para-aramid liner fabric: this would cause problems during ragging and is incompatible with most recycled uses for textiles. Garments will need to be simplified to make their end of use easier. This can be achieved by constructing them to aid end-of-use disassembly and limiting the material types used within the garment.

As an example, for protective denim jeans, the use of solely cellulose fibre within the jean would enable composting at end of life. This would require that the denim fabric be 100% cotton, the sewing thread made from a high-tenacity regenerated cellulose, the protective liner fabric made from a knitted cotton or high-tenacity regenerated cellulose, and the comfort liner from a continuous-filament regenerated-cellulose mesh fabric. Care labels could be substituted by printing important information directly onto the inside of the garment. At the end of life, this garment could be commercially composted. The buttons, studs and zippers could be sifted from the earth, washed and then recovered to make new products.

The construction of garments with low environmental impact will need to be considered in the future. Environmental impacts can occur during manufacture, use and disposal. The most obvious example of these impacts is in the use of synthetic fibres that have been shown to shed microfibres during use and laundering. Legislation is being formed for commercial laundries to limit loss of synthetic fibres into the environment. There is potential that this may extend into domestic laundering, with legislation written up against some fibre types or fabric constructions.

Fibres with high energy requirements during manufacture may also become too expensive to be commercially viable for motorcycle clothing construction. Typical high-energy manufacturing fibres are high-strength fibres including carbon, nylon, UHMWPE and para-aramid fibres. The environmental impact of these fibres and materials is in their construction, and they are unable to be easily unmade at end of life.

Other environmental impacts may result from chemical finishes. The most common problem in this area is fluorinated carbons for water repellence. Significant worldwide legislation has already seen the banning of some of these coating precursor materials due to significant environmental contamination from perfluoroalkyl and polyfluoroalkyl substances (PFAS).

2 Designing for injury protection

Injury protection is a key design consideration for motorcyclists' clothing. This chapter includes the following sections:

2.1 The distribution of injury risk in a crash.

2.2 Design considerations for providing abrasion protection within a garment; this section can be used by itself or together with Section 2.3.

2.3 The theory behind abrasion protection, providing additional information about the benefits and negatives of the materials detailed in Section 2.2.

2.4 How heat can be generated by friction during abrasion on a road surface, and design features to reduce the risk of associated injury or heat-induced material failure.

2.5 The causes of skin shear injury and the importance of slippery inner liners to mitigate its risk.

2.6 The mechanism of burst-resistance failure, and why some fabrics and seams are more prone to burst failure than others.

2.7 Tear-resistance testing of materials and how designing for strong burst resistance can also benefit tear resistance.

2.8 Testing of materials for cut resistance.

2.9 Impact protection, including the different types of impact protectors available, how they work, how decorative components may result in injury, and the importance of size and fit.

2.1 Injury risk zones

In motorcycle crashes, the frequency of different types of injury to each area of a rider's body follows a well-documented pattern. Large-scale studies of rider injuries and evidence of impacts or damage to their clothing have been used to identify the key areas of risk to a rider. These areas have been used to define the location, type and level of protection required in protective clothing. The risk zone diagrams also allow for stretch and breathable panels to be incorporated in areas of the garment at lower risk of impact.

There are two systems used for defining the injury risk to riders. The first is a four-zone risk diagram that is utilised by EN 13595 and MotoCAP. The second is a three-zone risk diagram that is utilised by EN 17092. The following section identifies each of the impact risk zoning systems.

2.1.1 Four-zone injury risk diagram

The four-zone risk diagram is based on the relative risk of crash impacts and injury to different areas of the body. It was developed from crash and hospital injury studies by Roderick Woods. The four-zone system has been validated several times through crash research over many years.

There are two mechanisms involved in protecting a rider's body. The first mechanism provides impact energy attenuating measures in Zone 1 to reduce the risk of bruises, sprains, dislocations and fractures by absorbing and distributing the forces of direct impacts to those most exposed areas. The second mechanism provides protection from injuries to skin and tissue across all zones by use of materials and construction that are resistant to abrasion, impact cut, tearing or bursting.

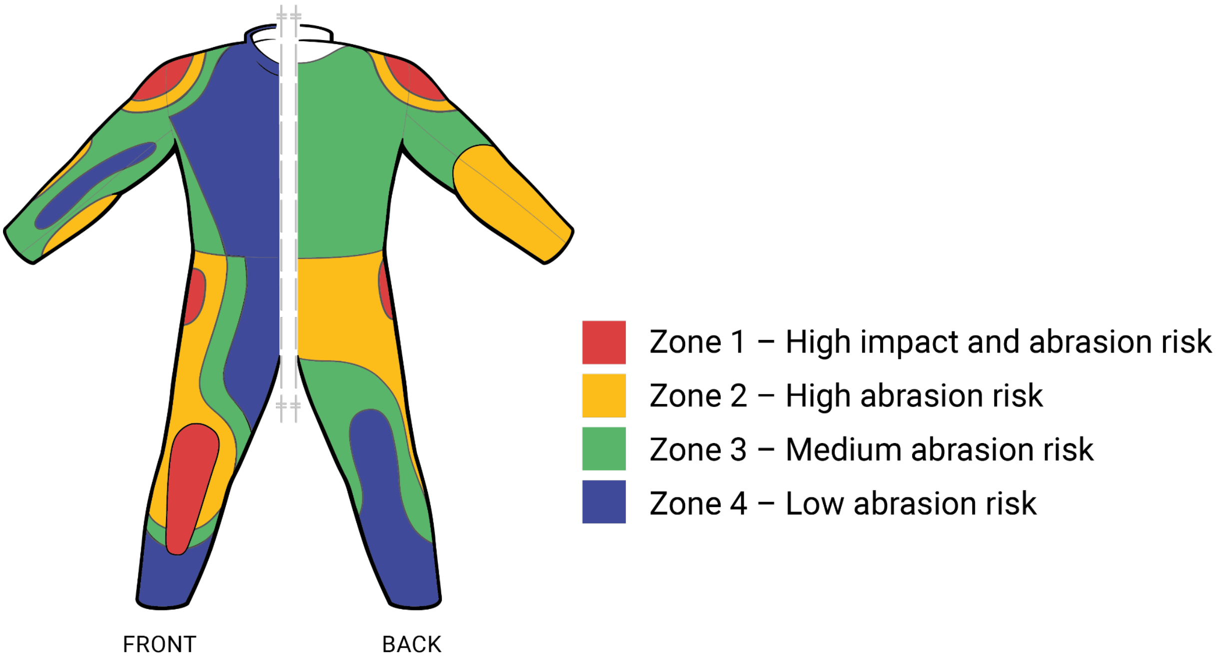


Figure 2.1: Four-zone injury risk diagram (EN 13595-1:2002).

The type and level of protection required in each zone are illustrated in Figure 2.1. They are:

- Zone 1: High risk of impact and abrasion injury
- Zone 2: High risk of abrasion injury
- Zone 3: Moderate risk of abrasion injury
- Zone 4: Low risk of abrasion injury.

The shoulders, elbows, hips and knees are classified as Zone 1, being the parts of a rider's body most exposed to direct high impact and abrasive forces. Zone 2 encircles Zone 1, having a similarly high risk of abrasion, burst and cut damage but less risk of direct impacts to the key skeletal joints. Zones 3 and 4 require successively lower levels of protection from abrasion, burst and cut damage. The lower risk of Zones 3 and 4 allow for the use of stretch and ventilation to be placed within a garment to ensure that it is comfortable to use.

2.1.2 Three-zone injury risk diagram

EN 17092-1:2020 was developed as a standard for the certification of non-professional riders' clothing. While drawn from the four-zone risk system, the new standard was based on the assumption that injury risk was lower for non-professional riders. The new system developed was a three-zone system (Figure 2.2).

Three zone templates are required for the new risk system. Class AAA garments have a section around the buttocks that defines an increased risk of abrasion injury, which is absent from the requirements for the lower performance classifications. Class A garments use the same risk template as Class AA, but do not require hip impact protection. An AAA-rated garment would be more likely to be worn by someone travelling at higher speeds, increasing their risk, whereas an A-rated garment is more likely to be worn in an urban environment at lower speeds, reducing the rider's risk.

The rationale for a three-zone system is not strong when the published work validating the four-zone system is considered. The validation of the four-zone system was done on all riders, not just on professional riders, so it should be applicable for all riders. It is recommended that the four-zone system is followed for all clothing design. Designing to the four-zone system will provide the highest level of protection to riders; importantly, it will also easily satisfy all the requirements of the three-zone system as well as MotoCAP.

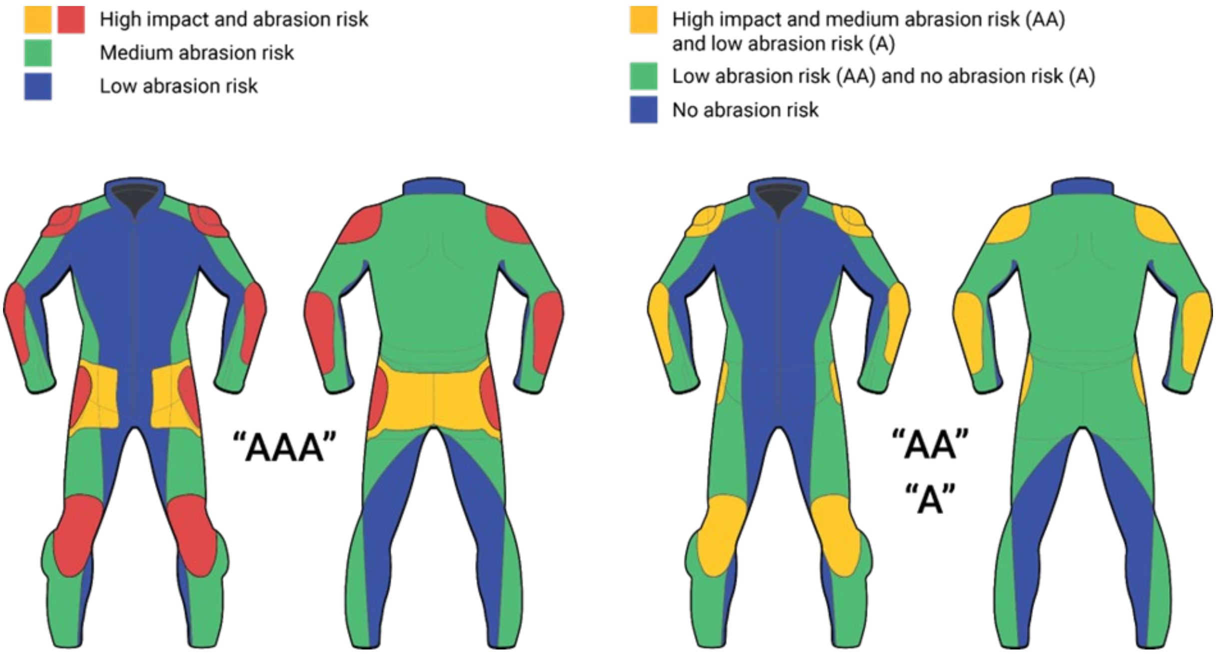


Figure 2.2: Three-zone injury risk diagram (EN 17092-1:2020).
Note: Class A garments do not require hip impact protection.

2.2 Abrasion resistance

Abrasion is the most common injury sustained by riders and is the injury against which motorcycle protective clothing is most effective. This section describes how abrasion resistance is tested and discusses how to enhance abrasion resistance through design features and the choice of key materials. The theory behind abrasion protection is provided in Section 2.3 and may be useful when applying the recommendations from Section 2.2.

2.2.1 Abrasion testing

Abrasion testing measures the time it takes to wear a hole through all layers of material in a garment. There are currently two impact abrasion test methods: the Cambridge and Darmstadt. Whereas both test impact abrasion, they take different measurements. The Cambridge reports the exact time in seconds to hole, whereas the Darmstadt reports only pass or fail at a specified speed. The Darmstadt results do not allow product developers to know at what point during the test their garment failed. The Cambridge test method specified in EN 13595-2:2002 is therefore the more appropriate method to assess materials for product development.

In the Cambridge test method, all layers of material are clamped around a test head, which is dropped onto a 60-grit belt travelling at 8m/s (28km/hr). The test stops when a copper wire placed under the test sample is broken. Testing should be done at 0°, 45° and 90° angles to the warp of the fabric or the centre line of an animal hide. Six tests in total should be performed. The test results should be corrected using the abrasion time for two layers of calibration fabric tested at the start or the end of the abrasion run. Variation in test results under this method is approximately 11% and may be higher for thin or stretchy materials.

In the Darmstadt test method, material samples are attached to three test heads on the arms of a rotating wheel. All layers of material in the garment are tested together, with each sample placed at a different angle (0°, 45° and 90°) to the warp of the fabric or to the centre line of an animal hide. The wheel rotates until it reaches the specified test speed. It is then detached from the drive and dropped, spinning, onto the concrete test bed. The test heads are allowed to slow to a stop due to friction between the material and the concrete surface. A sample is said to have failed at the specified speed if one or more of the three test samples has a hole larger than 5mm through all layers when it comes to rest. Variation in test results under the Darmstadt test method is not publicly available at the time of publishing.

When preparing garments for certification, it is important to use the relevant impact abrasion test method because they are not comparable. The European motorcycle clothing standard EN 17092:2020 utilises the Darmstadt impact abrasion test method, as detailed in clause 5.4 of the standard. MotoCAP utilises the Cambridge impact abrasion test method detailed in EN 13595-2:2002, following the MotoCAP test protocol.

2.2.2 Designing for abrasion resistance

Materials with low stretch have better abrasion resistance than more stretchy materials. Stretch materials are most vulnerable to damage when they are the first layer to contact an abrasive surface because they tend to grip and burst. Stretch materials should be limited to use in areas with low risk of impact or abrasion, such as Zone 4. Increased numbers of layers and thicker materials can be used to achieve abrasion protection where stretch is required in a higher-risk zone.

Low-stretch materials should be used in the high-risk Zones 1 and 2 of a garment. Woven fabrics and leather have lower stretch than knitted materials and are more suitable for these high-risk zones.

Layers of materials have better abrasion protection than a single layer of heavier weight. For example, two layers of a 600-denier nylon material will provide better abrasion protection than one layer of 1200-denier nylon fabric. Layering allows the first layer to take the load of the first impact, thereby protecting the inner layers and extending abrasion resistance time.

2.2.3 Leather

Leather is a natural material that can have good abrasion resistance and can be well-suited for high abrasion-risk areas. The abrasion resistance of leathers differs according to the type of animal from which the leather was sourced. Leather from cattle is highly abrasion resistant, whereas leather from sheep has very low abrasion resistance. Leather from the hides of other animals, such as goats, bison and kangaroos, may provide good abrasion resistance but should be assessed on a case-by-case basis using abrasion testing. Leather from the legs and belly of any animal should be avoided as these are weaker structures that provide lower resistance to abrasion.

The thickness of leather is a significant factor in the time to hole, as illustrated in Figure 2.3. Leather that has been artificially stretched, polished or split into thinner layers should be avoided. Perforating leather can also reduce its tear strength and abrasion resistance.

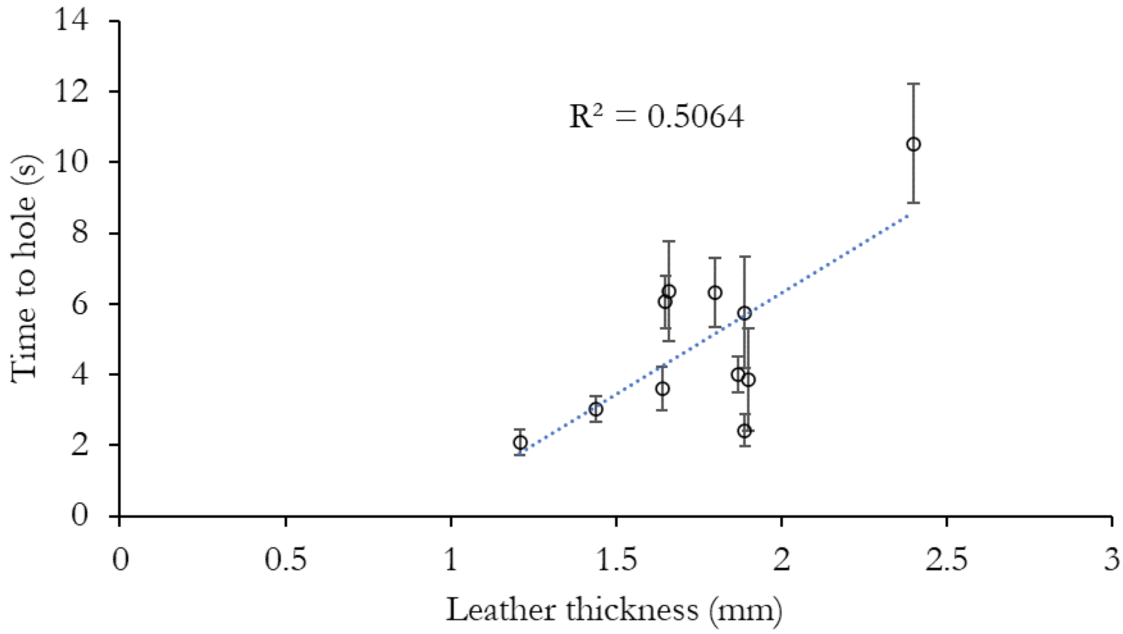


Figure 2.3: Leather thickness and its relationship with time to hole.

There are four main types of leather: full grain, top grain, genuine leather (suede) and artificial leather. Leather may also be perforated to allow ventilation.

Full grain leather

Full grain leather provides the highest abrasion protection of the four leather types. For areas of high abrasion risk, it is recommended to use at least one layer of full grain leather with a cumulative thickness of at least 1.5mm.

Top grain leather

The process to obtain the smoother surfaces of top grain leather reduces its abrasion resistance performance. For areas of high abrasion risk, it is recommended to use at least one layer of top grain leather with a cumulative thickness of at least 1.8mm.

Genuine leather (suede)

The lower thickness and different fibre structure of genuine leather makes it significantly lower in abrasion resistance. Genuine leather can be used in high abrasion-risk areas of the garment; however, it is recommended that at least two layers with a resulting thickness greater than 2.5mm are used. An alternative to improve the performance of genuine leather is with a >200g/m^2 fabric layer laminated to the inside layer of the leather. The use of a protective liner fabric such as a para-aramid knitted layer can also be used to improve abrasion performance.

Perforated leather

Perforated leather will have a lower abrasion and tear resistance than unperforated. The number, size and spacing of perforations determine tear strength and abrasion resistance. Smaller holes that are well-separated, (i.e. 1–2mm, with an 8–10mm grid spacing) have less risk of tearing or bursting in contact with a road surface.

Laminating a >100g/m^2 mesh fabric to the back of a perforated leather will improve its tear and abrasion strength. Perforations that overlay seams should be avoided because they provide a point of weakness for premature tearing or seam failure. It is recommended that perforations be restricted to the inner part of a panel to avoid seams and to better locate airflow for maximum effect within a garment (Figure 2.4).

Figure 2.4: Partially perforated leather panel, with no perforation at seams.

Artificial leather

Artificial leather is commonly used in fashion garments and upholstery. It is made by texturising a polyurethane coating over a knitted textile fabric. Artificial leather typically has low performance in abrasion and tear resistance. Coating a woven motorcycle protective fabric with polyurethane can improve protection, as can using a protective liner fabric under the artificial leather shell.

2.2.4 Textiles

Most textile motorcycle garments are made from nylon or polyester in addition to waxed cotton. Single layers of textile fabrics have low abrasion resistance due to the damage sustained on first impact with the road surface. Textile materials work best when there is more than one layer. This is clearly shown in Figure 2.5, where two layers of the 500-denier nylon (0.97±0.16s) and two layers of 500-denier mesh (1.18±0.11s) have a similar abrasion time to the single layer of 1680-denier nylon (1.04±0.14s).

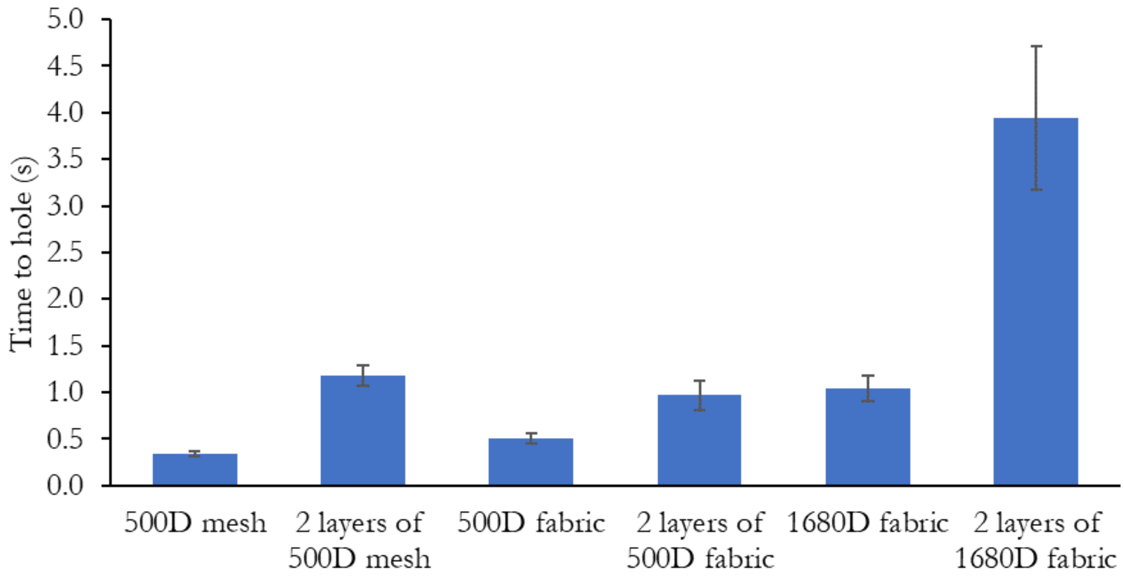


Figure 2.5: Abrasion times of different protective nylon 6 fabric constructions.

Nylon

The two main types of nylon used for motorcycle clothing are nylon 6 and nylon 6,6 (Cordura™). While nylon 6,6 has a higher tenacity and melting temperature, there is negligible difference in abrasion resistance between the two nylons, assuming a comparable fabric weight. However, nylon 6 fabrics have a lower melting temperature (220°C) than nylon 6,6 and can melt with extended abrasion times.

500-denier nylon fabric is the minimum thickness that should be used in single layers in the Zone 4 risk area. Using two or more layers of material is recommended in higher abrasion-risk zones.

Polyester

Polyester fabrics used in protective motorcycle clothing are comparable to nylon and have similar construction and requirements. Single layers used in low abrasion-risk areas should not be below 500 denier in weight. Two or more layers should be used in higher abrasion-risk zones. Polyester has a higher melting point at 265°C and a better resistance to melting than nylon 6.

Protective mesh fabrics

Protective mesh fabrics, made from either nylon or polyester, are suitable for use in motorcycle protective clothing. Increasing the thickness of a mesh structure will improve abrasion resistance. A 600-denier mesh is equivalent in abrasion time to a woven fabric of similar weight. As with other materials, layering mesh fabrics gives substantially better abrasion protection than single layers of greater weight. Layering mesh will reduce airflow through the mesh; however, air permeability will still be high in most cases.

Canvas and waxed cottons

Heavy-weight cotton and canvas fabrics can be used in either a waxed or unwaxed form. Waxing cotton has little effect on its abrasion resistance. A minimum fabric weight of $350g/m^2$ is recommended for low abrasion-risk zones of the body. In higher abrasion-risk zones of the garment, layering and protective liner fabrics may also be used to improve abrasion resistance.

2.2.5 Protective liner fabrics

As more casual-look clothing has been adopted for motorcycle riding, protective liner fabrics have become an important way of achieving abrasion protection for wearers. Protective liners can be placed within part or all of a garment to provide abrasion protection during a crash. For partially lined garments, the protection should cover all of the EN 13595 Zone 1 and Zone 2 areas of the garment. Attaching the liner fabrics at seams or to an inside garment liner helps to hide them from view.

Most protective liner fabrics are made from high-strength fibres, including:

- para-aramids (Kevlar™ and Twaron™)
- UHMWPE (Spectra™ and Dyneema™)
- aromatic polyester liquid crystal polymers (Vectran™)
- high-tenacity nylon (Cordura™).

Lower-strength fibres such as polyester, cotton and high-tenacity viscose may also be used with appropriate protective liner structures.

While the types of fibre used can influence abrasion protection, *how* it is used in the structure and mass per unit area of the fabric has much more influence. The best protective liner fabric structures are knitted terry loop and double jersey fabrics with a fabric mass of $350g/m^2$ or higher. Abrasion protection drops off very rapidly once the protective liner fabric is below $350g/m^2$.

The outer fabric plays an important part in the protective performance of an inner protective liner fabric. Figure 2.6a shows the different protection performance achieved by a para-aramid double jersey layer under a range of different outer fabrics. This graph shows that a small increase in abrasion resistance of the outer fabric from 0.14s to 0.52s takes the combination lined fabric abrasion time from 1.4s to 3.5s. While the fabric with 1.4s abrasion time might be suitable for low-risk zones, one with 3.5s would be more appropriate for the higher abrasion-risk areas of a garment.

Figure 2.6b shows that the abrasion resistance of the outer fabric is directly proportional to the performance of the lined structure. Effectively, the outer fabric must have sufficient abrasion resistance time to allow the protective inner liner to perform its role.

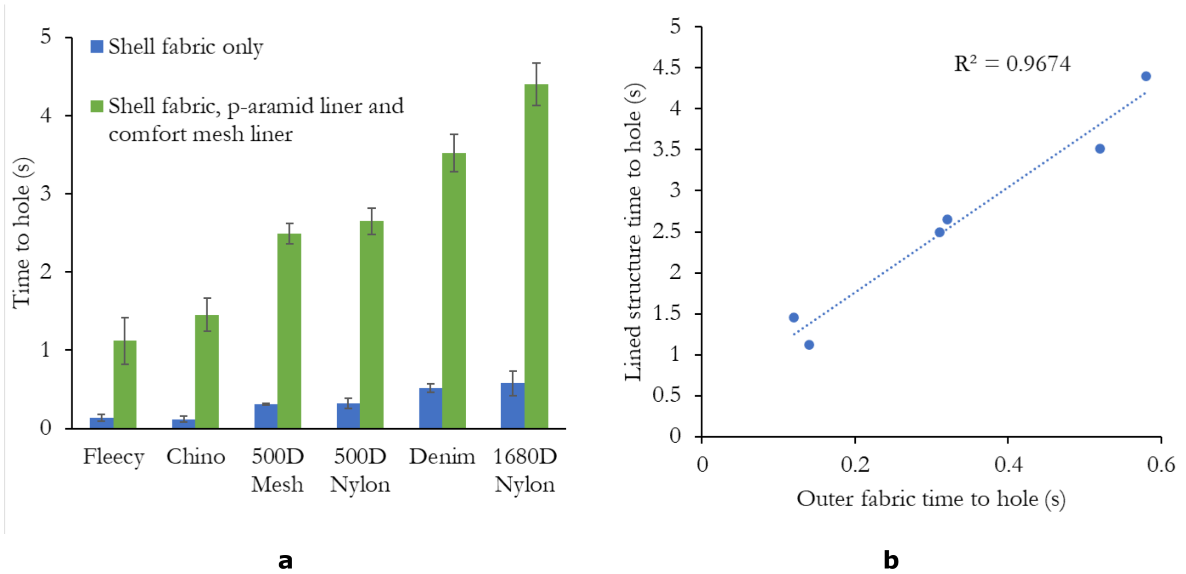


Figure 2.6: (a) Abrasion times for different outer fabrics and double jersey, para-aramid–lined outer fabrics, and (b) Relationship between outer fabric abrasion time and lined fabric abrasion time.

Denims

Denim fabrics are the most common outer shell material used with protective inner-liner fabrics. Denim fabrics with a tear strength above 80N and with a fabric mass of 350g/m^2 or higher are best for protective denim products. High-tenacity viscose and polyester fibres can be added to increase denim strength.

Fleecy fabrics

Hoodies with protective inner liners are becoming more common in the market and appear to be well accepted by riders. Fleecy fabrics typically have very poor abrasion resistance due to their stretch. The abrasion resistance of fleecy garments may be improved by placing a low-stretch intermediatory fabric (such as a single layer of 500-denier nylon) between the fleecy fabric and the protective liner. Another option is to use a fleecy fabric made from high-tenacity yarns that has been designed to have higher abrasion resistance. Fleecy garments should be fully lined because fleecy shell materials alone cannot provide enough abrasion resistance even for low-risk areas.

Stretch fabrics and leggings

Stretch fabrics face similar issues to fleecy fabrics when used with a protective liner fabric. Their stretch makes them more prone to burst failure and low abrasion-resistance times. For products such as women's leggings, the use of a low-stretch intermediatory material is not a viable option because it reduces garment comfort and impairs function. For applications of high stretch, a thicker double-layered stretch shell needs to be developed by the manufacturer, as there is not an off-the-shelf option currently available.

2.3 The science behind abrasion resistance

This section is designed to be read with Section 2.2 for readers who require more information about the basis for the methods recommended.

Abrasion protection is a vital component of motorcycle protective clothing. The interaction of a garment with the road is a two-step process. The first step is the impact with the road; the second is abrasion while moving across the road surface. For a material to provide good protection in a crash it must be able to withstand the forces of impact with the road surface and have good abrasion resistance while sliding across that surface. Impact damage typically occurs during the initial contact with the surface but may reoccur if the rider leaves the ground due to tumbling or an uneven road surface. The extent of abrasion damage to clothing is determined by the area of material in contact with the surface, and the force that is applied to the contact area.

2.3.1 Impact damage

Impact damage occurs when a protective material is forced into a road surface. The damage done will depend on the roughness (macrostructure) of the surface and the force of the vertical impact. Impact energy is governed by the mass and the vertical impact velocity of the material into the surface. The highest vertical impact velocity is likely to occur at the start of a crash. This is when the rider falls from the motorcycle onto the road surface.

In most cases, the force acting on the rider's body in a downwards direction is gravity. The vertical velocity at point of impact will depend on the distance that they travel in a downward direction from the highest point in their trajectory (Equation 1). If we consider the shoulder of a rider in a low-side crash, this is likely to be 1.5 to 2m of fall distance, depending on the height of the rider and the motorcycle. The fall distance and subsequent impact energy can be much greater in a high-side crash, as the rider is propelled upwards by the fulcrum effect of the motorcycle.

$$v = \sqrt{2gh}$$

Equation 1: *v* is the vertical impact velocity, *g* is gravity (9.81m/s^2) and *h* is the starting height above ground level of the impacting part of the rider's body.

Wind resistance is not included in this calculation, as the distance the rider will travel downwards should not see them accelerate to a velocity where wind resistance will influence their vertical impact velocity.

Additional impacts can also occur during a slide, if the rider tumbles or bounces after the initial fall. Each time the body reconnects with the surface while tumbling, further impact damage to clothing may occur, however those subsequent impacts will have less force than the initial impact. Tumbling is more likely to occur on an uneven road surface, where bumps and dips in a road surface can cause a rider's body to lift off and fall again. The impact damage is normally lower in energy than the initial impact, because the fall heights are relatively small.

Impact energy is also governed by the mass of the part of the rider that contacts the ground. The kinetic energy that is pushing the clothing into the surface of the ground is governed by the mass and velocity of the part of the body impacting the surface (Equation 2). As the mass is increased, so is the energy of the impact with the surface.

$$KE = \frac{1}{2}mv^2$$

Equation 2: *KE* is the kinetic energy of the impacting body part, *v* is the vertical impact velocity (calculated from Equation 1) and *m* is the mass of the impacting body part.

Impact energy is important as this may also cause the garment's material to be cut by sharp stones in the road surface, depending on the macro- and microstructure of the surface. High macrostructure can result in stones protruding from the surface that increase point loading, causing a garment to rapidly fail. High microstructure will result in lower gripping force of the material. Impact energy will also influence the amount of grip loading on fabrics and seams, which is discussed in more detail in the burst resistance section (Section 2.6) of this guide.

Roads with a relatively smooth abrasive surface such as asphalt have small aggregate components and are less aggressive in cutting and abrading fabrics. Road surfaces made with larger aggregate, such as with chip seal, are more abrasive and more likely to cut and abrade fabrics. In such cases, having two or more layers of protective materials over high impact-risk areas can reduce or delay failure from impact damage. The outer layer of fabric will take the brunt of the first impact, protecting the second layer from initial cutting. In a layered approach, the subsequent layers will have limited or no impact damage. These layers are then able to provide the full potential of their abrasion resistance for the duration of the slide.

2.3.2 Contact area

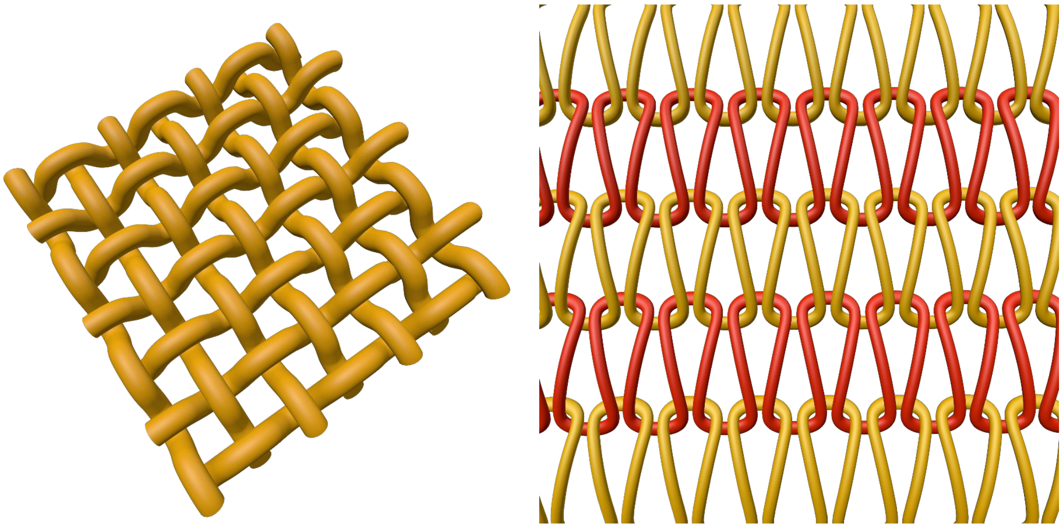
The size of the area of material in contact with an abrasive surface will influence the extent of abrasion damage. A larger contact area will distribute the abrasive load more widely than a smaller contact area. Abrasion damage is determined by the force applied and the area over which it is loaded. If the area is doubled while the force remains constant, the amount of force per unit area will be halved because the force is distributed over a larger contact area. As the contact area for a fixed force increases, the level of abrasion damage decreases.

The potential contact area of any material will vary according to its structure (i.e. woven, knitted, etc.) The microstructure of the material should be considered when determining the contact area with an abrasion surface.

Woven fabrics

Plain-weave woven fabrics typically have the lowest contact area of materials used in protective clothing. The over-and-under nature of the yarns used in a plain weave creates a series of peaks and valleys in the fabric microstructure. In the image shown in Figure 2.7a, the peaks of the yarns are the upper bends in the yarn structure. These peaks would be the areas of fabric to first contact an abrasive surface; they make up only 20% of the total fabric area. Wearing through the yarns in this small contact area will compromise the structural integrity of the fabric. The broken yarn will allow the fabric to pull apart, although there will still be a large amount of material that has not been abraded.

Woven fabric does have significant benefits against burst failure, discussed in Section 2.6, so should not be eliminated from protective clothing. Woven fabrics are better used in dual-layer designs to achieve effective abrasion resistance.



a b

Figure 2.7: Microstructure of (a) woven fabric, and (b) single jersey knit fabric.

Knitted fabrics

Knitted fabrics have a higher contact area in the face of their structure. While there are areas of open structure between the knit loops, there is a higher contact area in a single jersey knit than in an equivalent-weight plain-weave fabric. The large length of the loop on the face of the fabric engages with the abrasion surface (Figure 2.7b). This increases the area of yarn over which the abrasive force is distributed and increases the abrasion time to failure of individual yarns when compared to an equivalent plain-weave fabric.

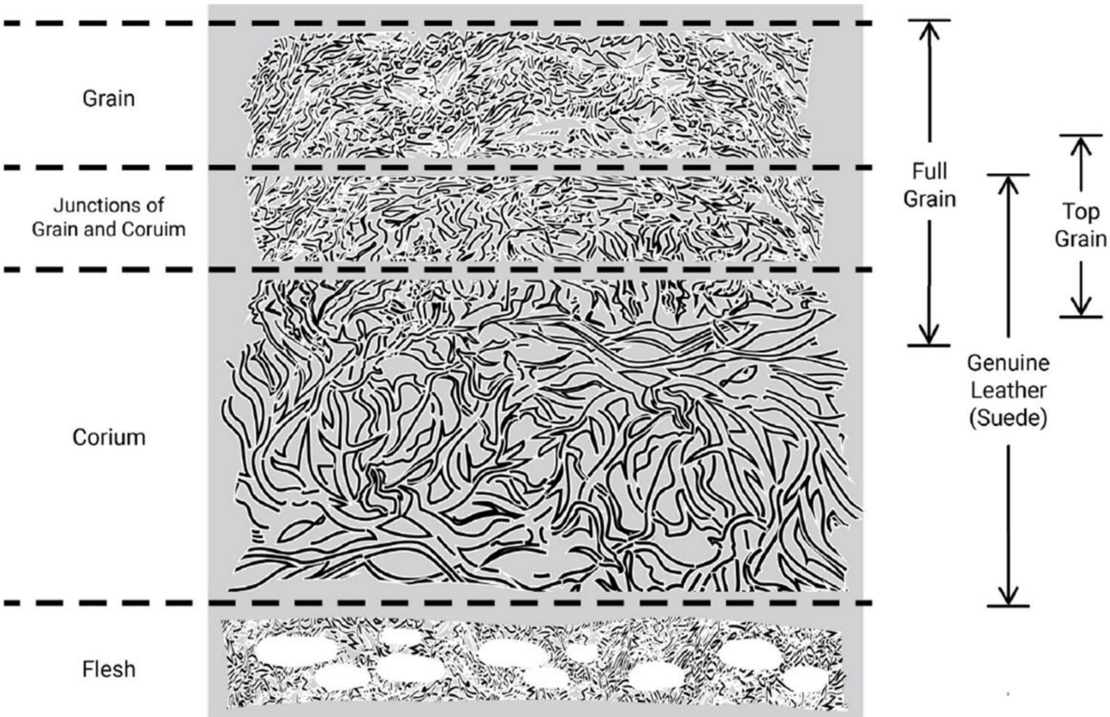
While knit fabrics have superior abrasion resistance to woven fabrics, they should not be used as an outer layer in a protective garment due to their lower resistance to burst. The reason for this is discussed further in Section 2.6. Knit fabrics work well in providing abrasion protection when they are placed as a secondary layer under a woven shell.

Knitted and woven terry structures provide the highest contact area within an abrasion surface of textile structures. The terry loop protruding from the fabric is drawn by the abrasion surface so that it lays flat on the abrasion surface. For dense piles, the loop provides a fibre/yarn layer that protects the parent fabric from abrasion. The loop must be abraded away before the parent fabric is exposed to abrasion. Higher loop densities provide better contact areas and hence abrasion resistance. Terry structures are normally used as a protective layer under a woven outer fabric, as their loop structure has poor aesthetic appeal to riders. Knitted terry fabrics also exhibit poor burst resistance, as do other knitted fabrics, making them unsuitable for shell fabrics.

Leather

Leathers have a high contact area within their abrasion surface. Leather is made up of a three-dimensional structure of chemically stabilised, intertwined collagen fibres. These fibres provide an almost unbroken contact area for abrasion. Their tight structure also holds fibres within the structure, resisting abrasion.

The distribution, size and orientation of fibres vary within the thickness of leather (Figure 2.8). The outer grain is made up of fibres that are very fine and highly entangled, and fibre orientations are parallel with the leather surface. This structure provides high abrasion resistance. At the junction between the grain and the corium, the fibres start to increase in size, are less entangled and transition from a horizontal to vertical alignment of the fibres. Abrasion resistance is reduced by both the fibre diameter and alignment change. The corium is made up of much larger fibres that are mostly vertical to the surface. The corium has the lowest abrasion resistance due to fibre orientation and diameter.



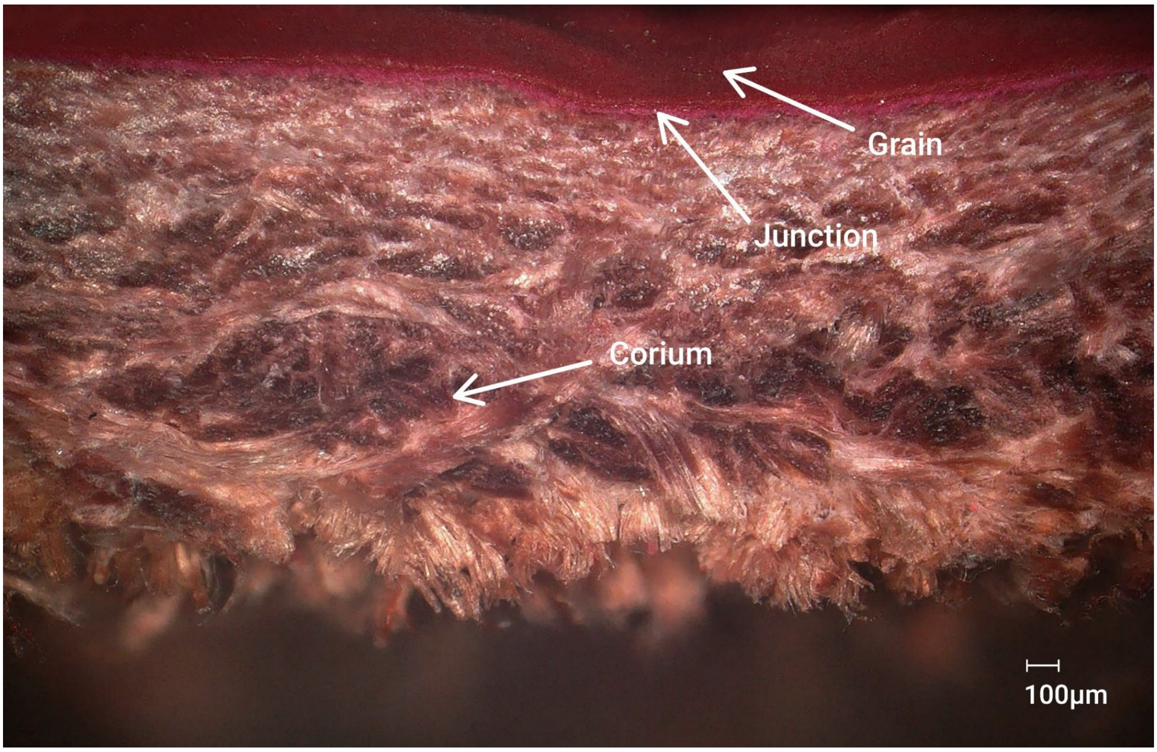


Figure 2.8: Fibre size and alignment within leather.

Full grain leathers contain the entire grain of the leather, along with the junction and some or all the corium. Full grain leathers have the best abrasion resistance of all leather types. Top grain leather is similar in composition to full grain leather, however its surface has been polished to improve its appearance and to remove imperfections from the animal's skin. As a result, top grain leather has lower abrasion resistance than an equivalent-thickness full grain leather. The lower abrasion resistance is due to the thinner grain layer. Genuine, suede or split leather is either a mixture of the junction layer and corium, or just corium. The larger diameter, orientation and lower entanglement of corium fibres results in lower abrasion resistance of these leathers.

The method by which leather is treated has a substantial effect on its abrasion resistance. The method of tanning will influence the leather's flexibility and abrasion resistance. Stretching of hides should be avoided during drying; air drying should be given preference over frame, vacuum and toggling. Processes like staking, which reduces fibre entanglement and bonding, will also reduce the abrasion resistance of the leather.

2.3.3 Layers

Abrasion resistance is improved when more than one layer is used. The improvement is generally greater than the sum of the abrasion time of the two single layers. An example of this is shown when testing a 400gsm cotton denim fabric. One layer of the denim lasts for 0.6 seconds before forming a hole, two layers of the same denim last for 2 seconds, and three layers last for 4 seconds. The significant improvement is caused by several factors:

- The outer fabric takes all the impact damage when the sample first hits the road, as discussed in Section 2.3.1.

- Even when a hole is worn through the outer layer, the edge of the hole will still be involved in the abrasion process and will distribute some of the abrasive load, reducing the force on the second fabric layer.

The results given in Figures 2.5, 2.6a and 2.6b show the advantage of applying different layers in a garment's construction. Further examples of the benefits of layering are detailed in Appendix A on abrasion.

2.3.4 Mechanism

The mechanism of abrasion damage is dependent on the macrostructure of the abrasive surface. This is determined by the size of the contact area between the garment and the road, and the proportion of fibres cut or pulled out of the material as it slides across the surface.

Road surfaces with small macrostructure, such as asphalt, cause less abrasion damage because the clothing remains in contact with the road surface during the slide, which distributes the abrasion load over a larger area. Road surfaces with large macrostructure, such as chip seal, cause greater abrasion damage because the garment cannot establish contact over its entire surface area, resulting in higher abrasion forces in those regions where contact is made.

Macrostructure type determines the mechanism by which fibres and larger particles are removed from a material's surface. The points on large macrostructure can pull fibres from textile and leather surfaces, and gouge hard surfaces. The guide concentrates on leather and textile materials, as these make up most protective clothing surfaces that are subject to abrasion damage. Harder materials, such as hard impact protectors, are not discussed; these are used sparingly in garments and typically have very high resistance to abrasion when present.

Chip seal surfaces typically have a large macrostructure The damage caused by this macrostructure is governed by the aggregate size and shape but may also be determined by the method of laying. Abrasion damage on chip seal is from fibre removal and occurs rapidly. In contrast, the damage from an asphalt or concrete surface with small macrostructure predominately involves wear damage to the surfaces of fibre and filament structures. Fibres are removed from the structure at lower rates, as the points present on the surface will be lower. While there is significant heat generated from friction during the abrasion, the materials last for longer before being holed.

2.4 Friction heat

This section introduces the mechanism of heat generation during the abrasion of a sample on a road surface.

2.4.1 Thermal generation and conduction

As a material moves over a surface at speed, it may generate heat through friction. This heat is generated on the outside surface of the material and can be transferred through the garment to the rider's skin. The thermal conductivity and structure of the material determine the rate of transfer into the material bulk and to the rider's skin. Highly conductive materials enable rapid conduction of heat through them. If the heat is transferred rapidly through the clothing, the rider may sustain burn injuries. This is a particular problem with metal fasteners, studs and other decorative metal items. Metals have high thermal conductivity with values above 50 $W.m^{-1}.K^{-1}$ (Table 2.1). If heat builds up, there is the potential for thermoplastic polymers to melt. Melting has been observed in the trailing edge of Cambridge impact-abrasion test samples made from nylon and composite fabrics based on UHMWPE.

Thermal generation and conduction vary on different road surfaces. Asphalt and concrete surfaces are more prone to heat generation than chip seal surfaces, whereas the rate of abrasion and fibre removal is lower for asphalt and concrete than chip seal. While fibres of a structure are moving over the abrasive surface, they are generating heat and transferring this into adjacent fibres in the material structure. The longer retention of fibres can result in thermal build-up in the protective material. In addition to the risk of burns to the rider, heat build-up can cause premature failure of structures due to lower tensile strength and melting. In a chip seal surface, the high rate at which fibres are torn from the protective material often limits the heat of abrasion conducting through the textile structure. Low thermal conductivities limit the rate that heat spreads when it is generated by friction during sliding.

Table 2.1 provides thermal conductivity values for several typical motorcycle clothing materials. Textile materials have lower thermal conductivity due to their higher rates of entrapped air compared to metal or solid plastic. An example of this is the higher thermal conductivity of solid cellulose (0.23 $W.m^{-1}.K^{-1}$) when compared with cotton textile fabric (0.03–0.06 $W.m^{-1}.K^{-1}$). In motorcycle clothing, the thermal conductivity of friction heat during abrasion may be somewhere between the solid material and fabric values, as some of the entrapped air is dispelled by the body crushing the materials into the road. Leather looks like a solid material however it has thermal conduction properties more like a textile fabric due to entrapped air within its fibrous structure.

Metals have significantly higher thermal conductivities than textiles and leather. In motorcycle protective garments, metal is predominately used for fasteners and embellishments. Metal objects should never be used where heat could be transferred to the rider's skin. The correct use of metal fasteners to avoid burn injury is discussed in Section 2.4.3.

Table 2.1: Thermal conductivity of different materials.

Material	**Thermal conductivity $W.m^{-1}.K^{-1}$ (measured at 20°C)**
Fibres	
Cellulose (solid)	0.23
Cotton textiles	0.03–0.06
Leather	0.14
Nylon 6 solid – polyamide	0.24–0.28
Nylon 6,6 solid – polyamide	0.25
Para-aramid (fibres and fabric)	0.04–0.13
Polyester solid (polyethylene terephthalate)	0.15–0.4
Polyester fabric	0.03–0.06
Metals	

Aluminium	239
Copper	386
Mild steel	50
Miscellaneous	
Air	0.024
Water	0.58

Note: The units for thermal conductivity are $W.m^{-1}.K^{-1}$ where W is energy in watts, m is distance in metres and K is temperature in Kelvins.

2.4.2 Melting

While sliding on less abrasive surfaces such as concrete or asphalt, a high heat from friction can be generated. Testing nylon 6 on an asphalt surface at 28km/hr found that enough heat was generated after 1.8 seconds to melt the nylon and form polymer beads at the trailing edge of the abrasion sample. Nylon 6 has a melting temperature of 220°C, so this indicates that the friction-generated heat was higher than 220°C.

Melting poses two risks to a rider. The first is that molten polymer can get onto the skin or into a wound, making the injury more severe. The second is that fabric strength is reduced as a thermoplastic material approaches its melting temperature, which can lead to premature failure and hole formation, exposing the wearer to the abrasive surface.

The thermoplastic polymers from which motorcycle clothing is commonly made include nylon 6, nylon 6,6 (Cordura™), polyester, and UHMWPE (Dyneema™ and Spectra™). Avoiding the use of thermoplastic polymers in garment construction is the best way to remove the risk of melting during abrasion. Melting polymers can be used in protective shell structures or liners, however they should always be separated from the skin using a non-melting layer or inner liner. The layer acts as a protective barrier to prevent any molten polymer from coming into contact with the skin. Low-melt fibres such as UHMWPE can be used within non-melt fibres as a reinforcing layer. The non-melt fibre then reduces the heat build-up in the melt polymer.

Leather and cotton are natural materials that do not melt and have good resistance to abrasion. Other materials that also do not melt and have reasonable resistance to abrasion include cellulose fibres – such as high-tenacity viscose, Lyocell™ and Tencel™ – when used in an appropriate fabric structure. Para-aramid fibres (Kevlar™ and Twaron™), and aromatic polyester liquid crystal polymers (Vectran™) are high-performance polymers that also provide high abrasion resistance.

There are several other melt-resistant fibres, including meta-aramids (Nomex™) and polybenzimidazole (PBI); however, these have not seen much adoption in protective motorcycle clothing.

2.4.3 Metal fasteners

When using metal fasteners in riders' clothing, manufacturers need to take care not to connect the outer shell to the inside surface of the garment, due to the risk of conducting heat to the wearer's skin. Any metal element on the surface of a garment can generate substantial friction heat when sliding on a road surface. Such heat may then be conducted through the garment, directly exposing the rider's skin to friction burns. Examples of metal fasteners where this can occur include press studs, buttons and rivets.

The most common place where this is observed in motorcycle clothing is in rivets and fly buttons in protective denim pants. The rivets and fly buttons are uncovered on both the outside and inside of the garment, providing a continuous metal path for friction heat transfer to the skin (Figure 2.9). The placement of an internal low-conduction material covering the inside of the rivet can remove this risk. Care should be taken to ensure that covering materials are not made from materials that melt, as this could increase the severity of the injury rather than alleviate the risk.

Figure 2.9: Uncovered metal fly button (left) and rivet (right) allow heat transfer to the skin in protective denim pants.

2.5 Skin shear injury

Skin shear injury is caused when a rider's clothing is pushed into their skin at the same time as it is dragged over the skin by the road surface. It is due to a combination of downwards pressure and friction, causing the skin or tissue to separate from the underlying muscles, tissue or bone. The injury may extend from the skin surface into the deeper layers of tissue, resulting in severe pain, disfigurement and scarring. It is often overlooked in motorcycle-crash injury studies due to the relatively low severity of most skin shear cases. However, skin shear can cause the deformation and death of skin and tissue cells. It can occur at all crash speeds and often occurs without clothing rupture. The most commonly known incidences of skin shear injuries are reported in aged care, where they are caused by dragging a person while they are in contact with a bed, a chair or the floor.

Historically, early motorcycle race riders would wear silk underneath their leathers to avoid shear between the leather and the skin in a crash. Provisions to avoid skin shear were adopted in EN 13595-1:2002, requiring linings to be able to slide freely against the outer shell in zones 1 and 2.

The lining material that is in contact with the outer shell should be slippery to reduce the risk of shear injury. Materials with a high coefficient of friction, such as denim and leather, are more likely to cause shear injury if they are next to the skin in a crash.

An effective way to reduce shear injury is in the use of a fabric liner that has a low coefficient of friction. Examples include silk, satin-finish and synthetic mesh fabrics. These fabrics are used as the inside liner of the garment against the rider's skin. The liner needs to be free floating so that the outer layer of the garment can slide against the slippery liner rather than the rider's skin.

2.6 Burst resistance

Burst failure is the rupture of a garment on impact with an abrasive surface. In most cases, burst failure occurs at a seam or garment closure, as these tend to be the weaker parts of the garment.

Burst failure occurs due to tensile loads that the abrasive surface and the movement of the rider's body exert on the garment. As a material impacts the ground, it is gripped by the surface macrostructure. The rider's forward momentum creates a tensile force into the clothing materials forward of the point of grip. In burst failure, this tensile force (grip loading) is high enough to rupture the seam, closure or fabric.

The downward impact speed, weight of the rider, speed of forward movement and stretch of the garment all have an influence on the propensity to burst. Higher grip is achieved when the force pushing the material into the road is high and the time available to achieve grip is long. The rider's weight and the speed of downward impact both influence the level of grip by increasing the extent to which a material is pushed into the abrasive surface. The speed of forward movement and the level of stretch within a garment both influence the time that grip can occur before the maximum gripping force is achieved and the tensile force applied. Slower riding speeds allow for more grip to occur before the tensile load is applied and hence increase the risk of burst failure. Stretch fabrics allow for more grip to occur while they convert forward momentum into fabric stretch. They will have a higher grip level when the tensile load is applied than an equivalent-weight non-stretch material, increasing their propensity for burst failure.

Burst failure can be avoided by using appropriately strong seams and fabrics.

Seams should be structurally strong. Seams that exceed strengths of 1,000kPa should be selected to provide adequate burst resistance in a garment. The details of preventing burst resistance in seams and closures is covered extensively in Chapter 5.

Burst resistance can be measured by either a hydraulic burst or tensile test method. The use of a hydraulically inflated diaphragm to load seams is the better of the two methods, as seams are loaded in all directions during the test. Tensile testing, however, only loads the sample from one direction (i.e. perpendicular to seam) so is not as comprehensive as hydraulic burst testing. Hydraulic burst testing is also more suitable for measuring stretch materials than tensile testing, which lacks repeatability with stretch materials.

There is a relationship between tensile testing and hydraulic burst testing that can be used to determine how a sample will perform on the alternative test (Figure 2.10). Appendix B shows the burst and tensile strength for different seam types in common motorcycle clothing materials. The equation in Figure 2.10 can be used to convert between burst strength (x) and tensile strength (y).

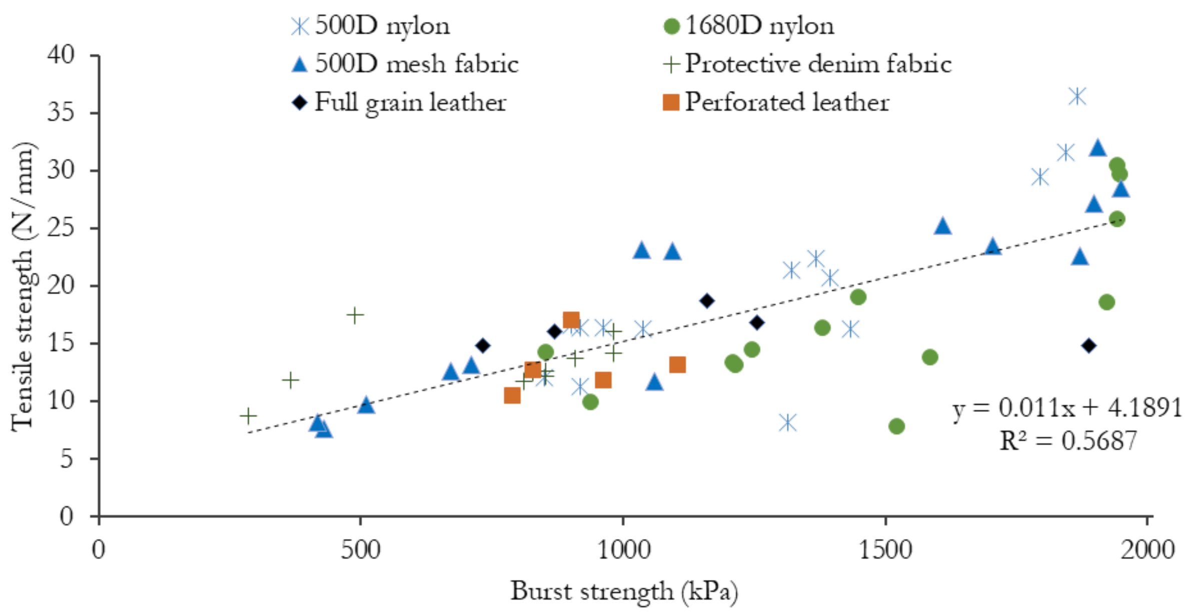


Figure 2.10: Comparison between hydraulic burst testing and tensile testing of seams in a range of garment materials.

The European motorcycle clothing standard EN 17092 utilises the tensile test method for measuring seams that is detailed in EN 13594:2015 Annex B for motorcyclists' protective gloves.

MotoCAP utilise the hydraulic burst measurement of seams utilising EN 13595-3:2002, following the variations detailed in the MotoCAP test protocols.

2.7 Tear resistance

Tear resistance is an important feature of motorcycle protective clothing. During the initial impact with a road, sharp objects such as torn metal, loose stones or sharp aggregate within the surface can cut or induce tearing. Cutting weakens the material surface while penetration of sharp aggregates into the material surface can initiate tearing. Fabrics with low tear resistance can, once cut, be torn open, forming a hole. The level of tear resistance will dictate the size of the hole formed. Tear resistance is measured using the wing rip method for textile materials and the single-edge tear method for leather.

Testing for EN 17092 has shown that there is a strong correlation between tensile strength of seams and tear resistance, indicating designing for good burst resistance (recommended in

Section 2.6) will also provide good resistance to tear. This same relationship is seen for tear strength and hydraulic burst resistance. MotoCAP does not test for tear resistance as it utilises the burst resistance score to quantify both seam strength and tear resistance.

The European motorcycle clothing standard EN 17092 utilises the method detailed in ISO 3377-1:2011 for the testing of tear resistance in leather and ISO 4674-1:2016 Method B for all materials other than leather.

2.8 Cut resistance

Cut resistance is the ability of a material to resist cutting when impacted by a sharp object. Cut resistance testing was part of the European Standard EN 13595-4:2002, which uses the impact cut method developed for butchers' clothing. This method measures the depth of penetration of a sharpened blade into the test specimen when travelling at a velocity of either 2.0 or 2.8m/s. It was added to reflect the conditions found on roads in certain parts of Europe where snow chains and studded winter tyres had eroded the sealant between individual pieces of aggregate and honed the aggregate itself to a sharp edge. Recent work at Deakin University has found that sharp aggregate surfaces on some dual-aggregate chip seals can induce cutting of clothing materials. EN 17092 does not measure cut resistance of motorcycle clothing materials.

The risk of motorcycle clothing being cut into by sharp aggregate can be reduced by:

1. **Using layering and cut-resistant materials.** Layering is the simplest form of resisting aggregate cutting damage in protective motorcycle clothing. Layering allows for the use of a sacrificial shell fabric that can resist cutting and acts to prevent damage to the secondary layer within the garment. The primary layer may provide some abrasion protection, however most of the protection comes from subsequent layers within the garment.
2. **Using cut-resistant fibres in the shell fabric**, such as the high-tenacity fibres mentioned in Section 2.2.5 that are often used in protective liner fabrics. These materials may also offer significant resistance to aggregate cutting. Metal threads or wires should not be used to resist aggregate cutting, because they can heat to very high temperatures during abrasion and pose a burn hazard to the rider.

2.9 Impact protection

Impact protection is provided to most motorcycle garments using removable impact protectors. Impact protectors are designed to attenuate impact forces through absorption and spreading the impact force. There are four types of impact protector widely available in the market:

- foam impact protectors
- shear-thickening polymer impact protectors
- structural impact protectors
- hard-shell impact protectors.

Each of these is described in more detail in Section 2.9.3, below.

Several crash studies that have found limb impact protectors substantially reduce the severity of injury in motorcycle crashes. Most of the limb impact protectors provided in garments have been certified to the European Standard EN 1621-1:2012, which is well recognised among riders. It is recommended that new garments are always fitted with currently certified impact protectors.

Back and chest impact protectors are also available in the market and are tested using similar equipment as for limbs but with modified conditions.

Back impact protectors are increasingly provided in some road-riding garments, with most tested to EN 1621-2:2014. However, while back protectors may reduce the risk of soft-tissue injury to the spine, they are less likely to reduce the risk of spinal fractures. This is because spinal fractures are most likely to be caused by flexion, axial load or compression forces along the spine either from the head or base of the spine.

Anecdotal evidence suggests riders place a high importance on the presence of back impact protectors in jackets. It is a benefit to riders to provide either a pocket to allow the insertion of aftermarket back impact protectors, or to provide a CE-certified back protector fitted within a garment. Foam fillers provide almost no protection from impact injury and riders often confuse them with certified protectors. The use of foam fillers in place of a certified back protector should be avoided.

Chest impact protectors are provided to a very small segment of the road-riding market, with most tested to EN 1621-3:2018. The requirement for chest protection for track riding is increasing, so track-orientated sports garments are recommended to have pockets available for aftermarket chest impact protection. The increased sale of adventure touring bikes has seen a similar trend of chest protector provision in adventure touring jackets.

2.9.1 Airbag jackets

Airbag systems were initially used in high-level competition. In the last few years, they have spread to the mainstream and into use by leisure and commuter riders. These systems predominantly cover the front and back of the torso, with some extending over the shoulders onto the upper arms. The sides of the ribs may also be protected by some designs.

The most effective tethered systems have been available to road riders globally for around ten years. These are activated by a lanyard that is attached at one end to a fixed point on the motorcycle in front of the rider, and at the other end to a spring-loaded trigger system. These garments release compressed gas into the airbag channels when the lanyard is pulled to its fullest extension and with a minimum of force.

More recently, tethered systems have been joined by fully electronic systems, which feature accelerometers and other sensors that inflate the garment when certain movement force thresholds are exceeded. The electronically deployed systems have faster reaction/inflation times than tethered systems, protecting a rider earlier in a crash; however, they require power to work and need regular charging. Their explosive charge system for releasing the inflation gas requires manufacturer intervention for reloading, whereas the lanyard-style systems are commonly serviceable by the user. Lanyard-style airbag jackets are certified under EN 1621-4:2013, while a new standard is being developed for electronically triggered devices.

2.9.2 CE certification

There are two levels of protection certified for limb impact protectors under the European Standard EN 1621-1:2012. Level 1 is the lower-performing product, while Level 2 is higher performing.

Level 1 impact protectors require an average attenuation force of below 35kN and no single strike above 50kN to achieve certification. Level 2 impact protectors require an average attenuation force of below 20kN and no single strike above 30kN to achieve certification.

Limb impact protectors are certified to protect a specific body part, with descriptors used to specify the certified limb (Table 2.2). Some impact protectors may be certified to be suitable for multiple limbs. There are two different sizes of limb impact protector. Type A are smaller in size and are appropriate for smaller riders up to size medium in men's. Type B are larger in size and are suitable for men's size large and larger, although some taller and more heavily built riders may find that even Type B protectors offer marginal or inadequate protective coverage. Most companies will only manufacture and certify one size of limb impact protector, so it is better to select the Type B if only certifying to one size.

Table 2.2: Impact protector limb definitions.

Limb	Descriptor
Shoulder	S
Elbow and forearm	E
Hip	H
Knee and upper tibia	K
Knee; upper and middle tibia	K + L
Leg below the knee and upper tibia	L

Impact protectors are subjected to a range of conditions including low and high temperatures, as well as sweat and rain. Impact protectors are made from polymers that may have different properties at different temperatures. For example, a foam polymer that protects adequately at 20°C may become brittle at 0°C and soft at 40°C. Garments designed to be worn in very cold or hot environments should have impact protection certified at the additional lower or higher test temperature. Prolonged exposure to moisture may cause some polymers to degrade.

The test uses a tower with a 5kg striker dropped along guide wires so that it has 50J of energy on impact. Testing is conducted at 23°C and 50% humidity. Testing is also conducted under the same testing conditions after 72 hours of hydrolytic aging at 70°C in a wet condition. Additional testing at low and high temperatures may also be conducted and is delineated on the impact protector with either a T- or T+ marking. Low-temperature testing (T-) is conducted after 24 hours of storage of the impact protector at –10°C, with the impact protector tested within 2 minutes of leaving the cold environment. High-temperature testing (T+) is conducted after 24 hours of storage of the impact protector at 40°C, with the impact protector tested within 2 minutes of leaving the hot environment.

EN 1621-1:2012 requires that labelling must provide information on the protector's performance and must be permanently affixed to an impact protector (Figure 2.11). EN 1621-1 was reviewed in 2012 and impact protectors marked with an older standard number (such as EN 1621-1:1997) are no longer certified for use in new garments.

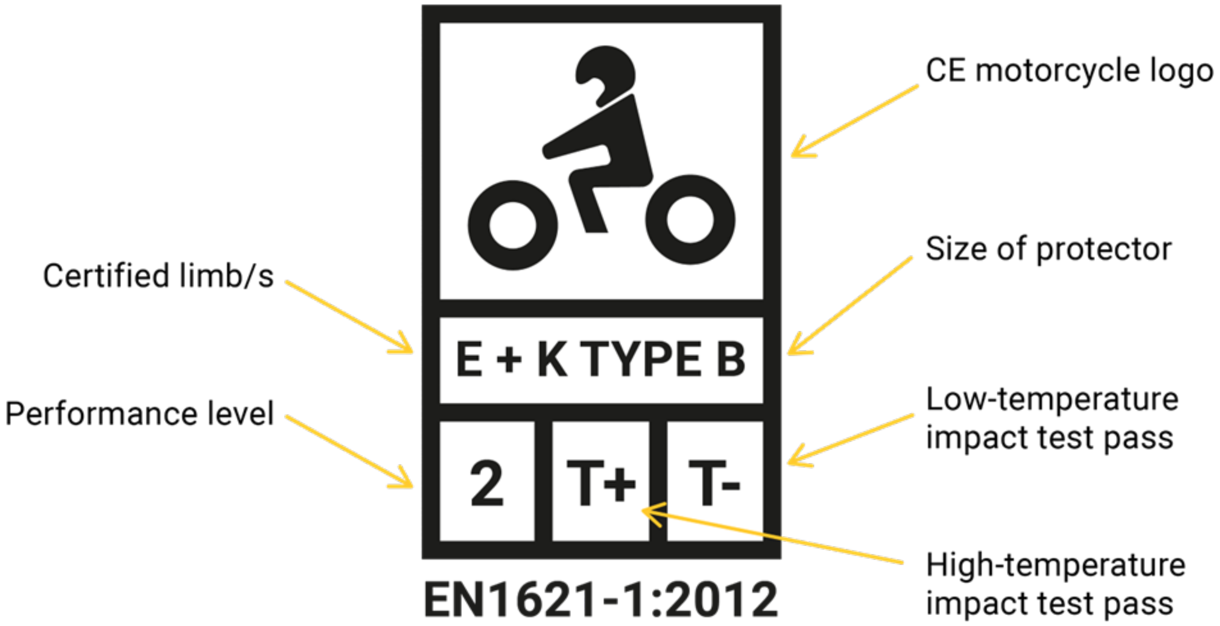


Figure 2.11: Description of the CE elements on the label of a limb impact protector.

2.9.3 Impact protector types

Foam impact protectors

The most common type of impact protector used in motorcycle protective clothing is a closed-cell polyurethane impact protector (Figure 2.12). These are made using an injection moulding process and are low cost and easy to manufacture. Foam impact protectors absorb impact energy by crushing open or closed cells within the foam. Several manufacturers have started to use mesh structures in their foam impact protectors, to make them lighter and more breathable (Figures 2.12b, 2.12c). These impact protectors are more suited to low-impact energy absorption, as they become quite thick and less flexible when used for high energy absorption.

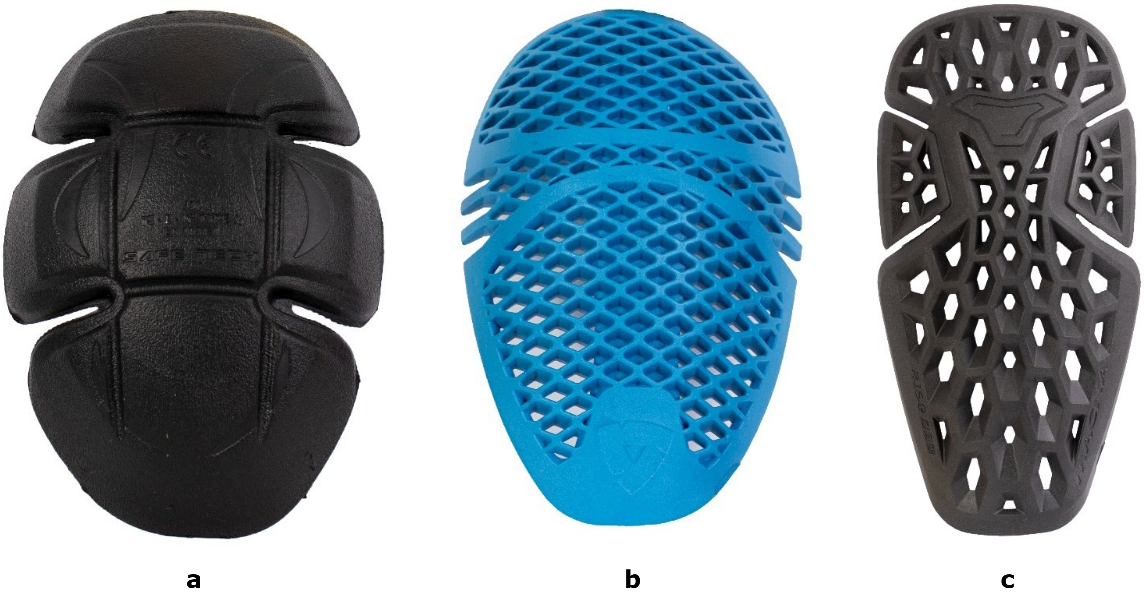


Figure 2.12: Closed-cell foam impact protectors in (a) solid, and (b, c) mesh formats.

Shear-thickening polymers

The first shear-thickening polymer impact protector in the market was made by D3O (Figure 2.13a). A shear thickening polymer is relatively soft and flexible in its unloaded state. On the application of high shear, such as that applied during impact, the polymer changes to a hard state. Impact energy is absorbed in this transition as well as spread over a larger area of the limb. This enables manufacturers to make a relatively thin and flexible structure with high energy attenuation. Increasing protection levels can still have a negative effect on thickness and flexibility (Figure 2.13b). In Level 1 format, these impact protectors are suitable for all limb applications.

Figure 2.13: Shear-thickening polymer impact protector – (a) Level 1, and (b) Level 2.

Structural impact protectors

Structural impact protectors are designed so that the shape and geometrical pattern of the impact protector attenuates impact energy (Figure 2.14). The energy is attenuated by a structural change of the patterned element during impact. Most involve columns protruding from a flat plane. This design enables high flexibility with reasonable impact energy attenuation.

Structural impact protectors have gained great interest since the end of 2019. Thin-walled column structures absorb more energy than solid columns, as energy is absorbed in crushing the tube as well as crushing the foam cells. Structural impact protectors are highly suited for use in the knees of pants where high flexibility is required. They are also appropriate for all limb impact protector applications.

Figure 2.14: Structural impact protectors.

Hard-shell impact protectors

Hard-shell impact protectors are an older technology that are not as widely used due to their lower flexibility. They are normally constructed from a hard plastic shell over a textile (Figure 2.15a) or foam (Figure 2.15b). The hard shell disperses the impact force over a larger area of the underlying foam, which then absorbs the impact energy. Careful design is needed to ensure that the hard shell is not at risk of fracturing on impact, as this could introduce a cutting and stabbing risk to the wearer. A combination of a hard shell over a polyurethane foam or shear thickening polymer foam could be used to provide good protection; however, the structure would have limited flexibility and not be suitable for all limb protection applications.

a b

Figure 2.15: Hard-shell impact protector with (a) a hard plastic shell over a textile foam composite, and (b) with a closed-cell foam over a textile.

2.9.4 Impact protector selection

When selecting impact protectors, it is important to maximise limb coverage and impact energy attenuation. Most impact protector manufacturers only obtain EN 1621-1:2012 certification for one size of impact protector, due to the combined cost of tooling, testing and certification. Where possible, it is better to use a Type B impact protector over a Type A, as this will provide increased coverage for all wearers and slightly improved coverage for taller and more heavily built riders.

Ensure that the impact protector provides its full impact protection over the entire risk zone. Some impact protectors taper on the edges and have reduced protection over a portion of the protection zone, reducing their effectiveness. Check the coverage of the impact protector with the relevant limb Type B template (EN 1621-1:2012). Where possible, select impact protectors that have a coverage larger than this template.

Protection levels should be selected according to the riding style of the garment. Level 1 impact protectors can be appropriate for lower-speed riding in an urban environment. Level 2 impact protectors are preferred for use in all garments, but particularly at higher speeds or in an off-road environment, where impact energy is higher or impact events are more likely. As most riding, and most crashes, occur in fine weather, impact protectors should be selected that have also been tested at 40°C (T+) and are more suitable for warm conditions.

Riders are more likely to permanently remove impact protectors if they cause discomfort or hinder the use of the garment. Ensure that the limb protector selected has the appropriate flexibility and fit to be worn in the clothing in all use conditions. For pants, it is better to select a structural or shear-thickening impact protector with high flexibility, as impact protectors with low flexibility can potentially hinder movement on bike and off bike. For jackets, ensure that bending and moving the arm does not result in discomfort to the point of the elbow from the hard surface of the impact protector. Consider the use of Velcro attachment systems where the coarse side of the fabric is facing away from the wearer and cannot touch the skin, which can otherwise prove extremely uncomfortable and irritating, distracting from riding concentration.

2.9.5 Injury risk from hard embellishments and fastenings

Hard elements fitted to the internal and external parts of clothing may cause injuries if pressed into the body from a crash impact. Items that may cause injury are hard and sharp or bulky in nature and include buttons, buckles, badges and embellishments. If used in garments, such elements should have a low profile to minimise the risk of causing injury to the wearer. Hard elements with large flat surface areas pose less of a risk provided they do not shatter on impact, which could result in injuries from shards stabbing or cutting. An example of a metal spike embellishment that may be unsuitable for motorcycle clothing is shown in Figure 2.16.

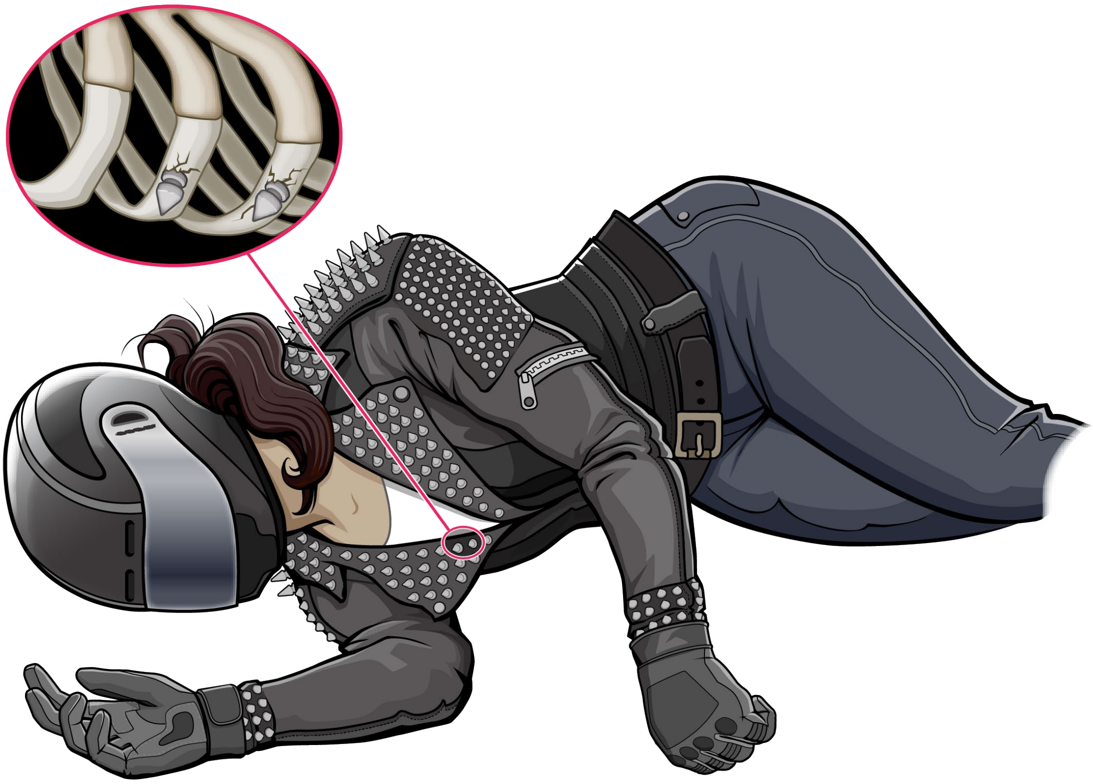


Figure 2.16: Example of a metal spike embellishment that may fracture ribs during impact.

3 Designing for thermal management

Thermal management, including ventilation and breathability, are important features in the design of motorcycle protective clothing. This chapter breaks down the elements required to design a garment suitable for use in different riding conditions, and includes the following sections:

3.1 Basic elements when designing for thermal comfort under hot, cold and wet conditions.

3.2 The science of thermal comfort, breathability and moisture vapour transfer for motorcycle clothing.

3.3 The theory behind thermal resistance and how it should be considered when designing clothing to be used in a cold environment.

3.4 Air permeability in motorcycle clothing and how it can be used to make garments more suitable for use in warmer riding environments.

3.5 The theory behind resistance to water penetration, and the benefits and disadvantages of water-repellent finishes and water-resistant membranes.

3.1 Thermal comfort

Thermal comfort refers to the body's ability to maintain normal core temperature, which is essential for the regulation and functioning of bodily organs, particularly the brain. When a rider is either too cold or too hot, they may become irritable or less alert with slower decision-making and reaction times.

Thermal discomfort can also impair a rider's ability to control the motorcycle and their enjoyment of the ride. As a result, many riders choose to ride unprotected in hot conditions because their protective clothing is too uncomfortable.

Clothing that is wet or damp may cause rapid chilling because of the way water conducts heat away from the body. This is a particular issue for riders in any weather because, whether damp from rain or sweat, the wind accelerates the chilling process.

Thermal comfort can be controlled by thermal insulation, together with the ability for the clothing materials to allow moisture vapour to escape into the environment.

3.1.1 Hot environments

Thermal comfort in warm environments is more difficult to achieve than in cold environments, because the materials that provide abrasion protection are often thick and highly insulating. In a warm environment, the body expels excess metabolic heat as sweat, which must evaporate away from the skin. Garments must be water-vapour permeable to allow the transmission of moisture, which, if trapped on the skin, can block the sweating function and thereby inhibit the regulation of core temperature. Thermal comfort is easier to achieve with textile than leather garments because fabrics tend to have greater breathability.

The keys to designing motorcycle clothing for warm environments are:

- breathable materials
- minimal layers
- heat-reflecting colours and treatments to the outer shell (e.g. UV)
- providing opportunities for heat to escape and for cooler air to enter through ventilation.

Water-resistant liners

Water-resistant liners and laminated water-resistant layers reduce air and moisture vapour transmission and therefore thermal comfort in hot environments. Care should be taken to ensure that water-resistant liners:

- are only used when necessary
- have been laminated to the garment shell
- have a high moisture vapour transfer rate.

Mesh and perforated leather panels

The easiest way to achieve thermal comfort in hot conditions is with the use of mesh and perforated panels in part or all of a garment. Garments comprised of full-mesh fabrics or perforated leather cannot control airflow, which is a serious limitation, with potential to cause excessive sweating or chilling. In addition, some mesh materials have lower abrasion resistance, increasing injury risk for riders wearing those garments. The addition of knitted protective liners and layering of mesh fabrics can improve abrasion resistance in high abrasion-risk zones.

Controllable vents

Controllable vents offer a more effective approach, allowing riders to manage their own thermal comfort. Vents are normally controlled by fasteners to hold the vent closed when not in use. Zips and Velcro provide the best form of closure for controllable vents because they can be partially or fully opened to control the volume of airflow. Vents in the chest and back of jackets, and on the upper legs in pants, provide the most effective locations for cooling.

It is important to provide at least two openings to allow airflow through the garment, otherwise ballooning can occur. An example of ballooning is when riding speeds force air into chest vents when there are no back vents to allow the air to escape. In such cases, the air may be trapped due to snug-fitting neck, wrist and waist closures. The low air pressure formed behind a rider can also assist in drawing air from back vents. Vents, including controllable vents, should never be placed in a Zone 1 or 2 area because they are weak points in the garment's construction and may compromise injury protection if fasteners fail on impact.

Air-permeable materials

The use of air permeable materials in conventional clothing can enhance wearer comfort both on and off the motorcycle. Protective denim jeans have displaced much of the market for leather and textile pants due to their improved rider comfort. The moisture-absorbing capabilities of cotton fibres in denim, combined with the high air permeability of a knitted protective liner, means that moisture vapour can easily be released from the garment.

Riding shirts and hoodies can also be better alternatives to conventional jackets under hot conditions, due to the greater air permeability of their textile structure compared to traditional motorcycle jacket materials. However, it is essential that they have sufficient abrasion and burst resistance to provide wearers with protection from injury.

3.1.2 Cold environments

Thermal comfort in a cold environment may be best managed by layers of warm underclothes, although excessive layers may restrict the rider's movement. Several design elements incorporated into jackets and pants can make thinner, warmer garments for riders. Features such as closable vents and snug fittings at wrists, collar and waists can reduce gaps for air to be forced into the garment. In addition, shell materials, which have low air permeability, may be used to reduce the transmission of warm air out of the garment and of cold air into the garment.

Vent and closures

Garment closures should be selected to minimise entry of air and moisture. Zips and Velcro provide better airtight closure than buttons and press studs. Vents should be designed to ensure there are no air leaks when fully closed. Zips that have low air permeability when closed should be used for these garments. Closure zips on the chest, which are covered by one or more overlapping layers impermeable to air/water, will resist air penetration of the garment more effectively. Adjustment should also be provided to cinch down the materials around cuffs, collars and waists, to further minimise air entry and exit from the garment.

Thermal liners

Removable thermal liners are generally made from a quilted fibre matting designed to trap air within the garment structure. This entrapped air retains body heat close to the skin, which improves thermal comfort. Air-impermeable and water-resistant layers may also be incorporated to further restrict air movement; however, it is better for water-resistant layers to be laminated to the shell fabric for optimum moisture vapour transmission. Thermal liners can be made to attach onto the inside of a garment. Making the thermal liner visually appealing, and able to be worn as a standalone garment when not attached within the parent garment, increases the benefit to a rider when they are off the bike.

Rain jackets

A lightweight water-resistant garment designed to fit over the protective garment can improve warmth retention. A water-resistant barrier also stops forced air convection, improving comfort for the rider in cold weather. Such a garment can maintain branding when worn and can be designed to be easily stowed when not in use.

3.2 Moisture vapour permeability (MVP)

Moisture vapour permeability refers to the capacity of a garment to allow moisture vapour to pass through a garment. Moisture vapour is the main conduit of heat out of the body, so entrapment of moisture vapour may cause the wearer discomfort. Entrapment of moisture vapour in a cold environment may also result in condensation and garment wetting, which may increase wearer discomfort.

Breathability is the measure of moisture vapour permeability (MVP) of a material measured in g/m^2.24hr. MVP is normally measured using a cup method, where the material or materials are placed over a cup that contains a desiccant in a controlled humidity and temperature chamber (Figure 3.1). The increase in mass allows the moisture vapour travelling through the material to be measured. An alternative method is to place the material over a container of water in a sealed container in the presence of a desiccant. The mass change of the water is monitored to determine the MVP. Both methods provide similar numbers for MVP for a material or set of material layers. MVP can vary depending on the composition of the materials.

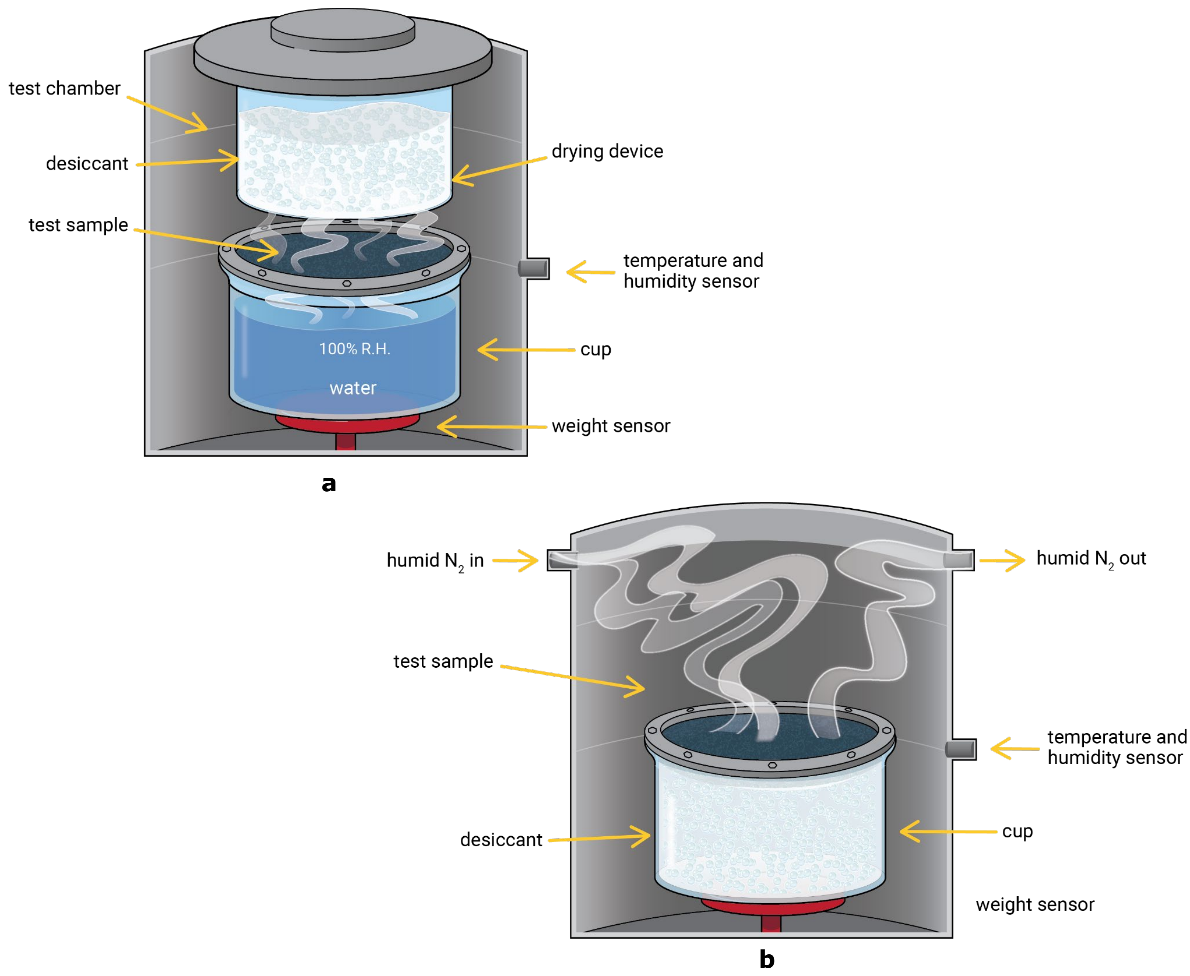


Figure 3.1: MVP measurement using gravimetric upright cup in (a) wet-cup and (b) dry-cup modes.

Breathability can also be expressed as the moisture vapour resistance (R_{et})of a membrane measured in Pa.m^2/W. This is measured using a sweating guarded hotplate at a controlled humidity and temperature. The hotplate works by measuring the amount of heat required to maintain skin temperature of the hotplate. Water passing through the MVP membrane acting as an artificial skin evaporates, which absorbs heat. If moisture vapour can easily permeate through the material being measured, then it will result in more heat required to maintain skin temperature. If the moisture vapour is trapped under the material, then less heat is required to be added to maintain equilibrium. The lower the R_{et}, the better the breathability of the garment.

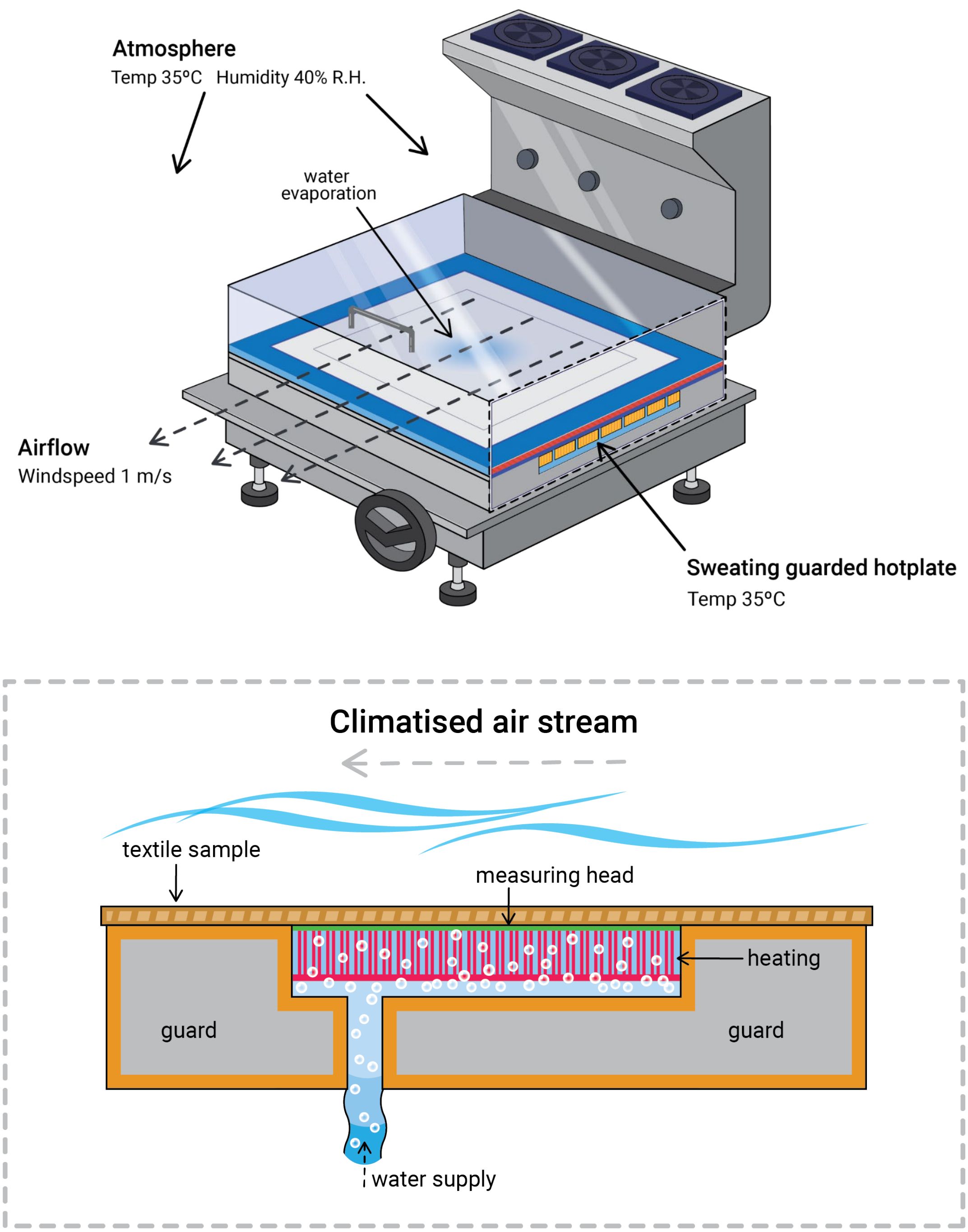


Figure 3.2: Sweating guarded hotplate (upper) and cross-section of a sweating guarded hotplate (lower).

Figure 3.2 shows a side cutaway of a sweating guarded hotplate. The central plate is heated to skin temperature, and heat loss is directed through the top of the measurement plate. Heat cannot be lost through the sides or bottom due to the heated guard plate below and surrounding the measurement plate. The energy fed to the measurement plate is recorded over time to enable the R_{et} to be calculated. The guard plate is kept at the same temperature as the measurement plate to avoid heat loss or gain from the guard. Water galleries through the plate allow water to travel up to the guard surface and sit under the MVP membrane. The MVP membrane releases moisture vapour at a controlled rate, to simulate sweating of the plate. A controlled flow of air is passed across the surface of the plate to enable removal of moisture vapour and maintain temperature and humidity conditions at the inner surface of the material being measured. A test sample harvested from a garment is placed on the hotplate for measurement. It should contain all of the garment layers to provide a complete picture of the garments performance (Figure 3.3).

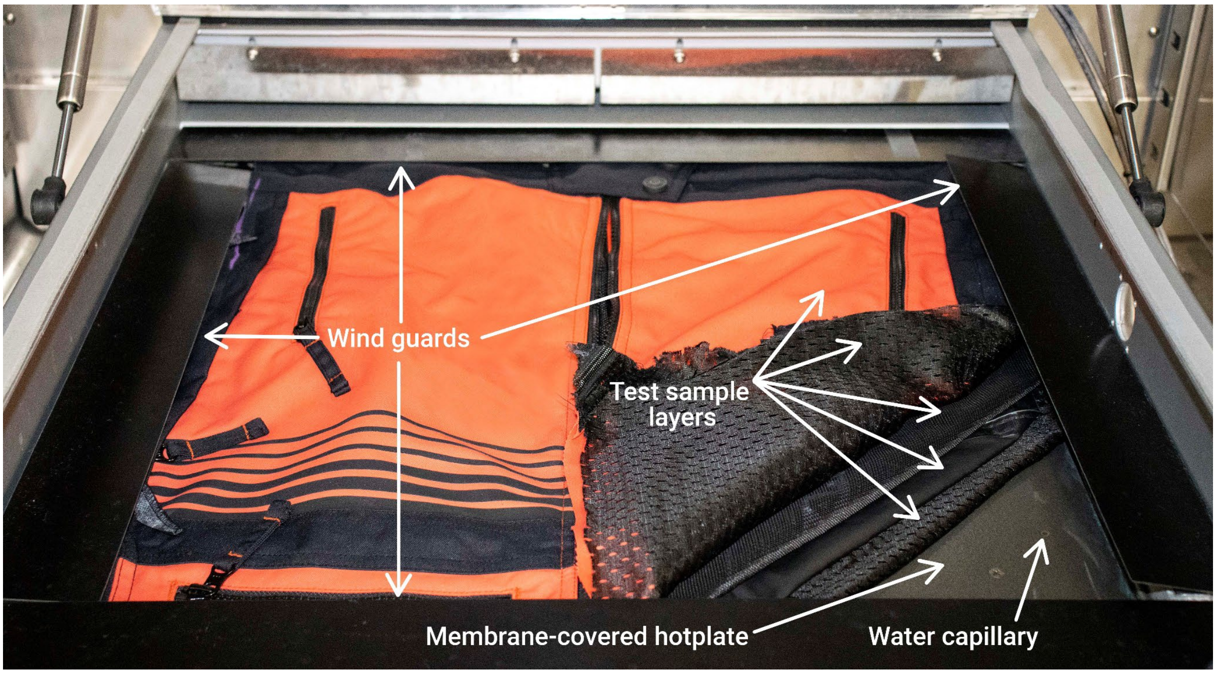


Figure 3.3: Jacket panel placed in sweating guarded hotplate with one corner folded up to show hotplate surface.

MVP is most important in water-resistant clothing, as treatments and membranes can restrict the escape of moisture from next to the skin. The effects of replacing a breathable membrane with an impermeable plastic film show the importance of MVP in wearer comfort. The plastic film would trap the moisture released from the wearer's body, causing it to build up in the area between the skin and the clothing. This increased humidity traps heat and increases wearer discomfort. When humidity levels become high enough, moisture vapour can condense, wetting the wearer and their undergarments, potentially restricting the body's management of core temperature.

MVP is not measured as part of EN 17092:2020. MotoCAP measures R_{et} with a thermal sweating guarded hotplate following ISO 11092:2014 and uses this measurement along with the thermal resistance (R_{ct}) to provide a thermal comfort score and breathability rating. A range of different materials have been measured for moisture vapour permeability; results for these are given in table form in Appendix C.

3.3 Thermal resistance

Thermal resistance is a measure of the insulating properties of a garment in a dry state. Thermal resistance is often expressed as R-values or R_{ct}. R-values are well known as they are applied to a range of different areas including clothing, bedding, building materials and thermal insulation. Designing with thermal resistance in mind is most important when designing for gear that will be used in a cold environment. In cold environments, a higher R-value for clothing is required to improve thermal retention.

Thermal resistance of clothing materials is governed by the thermal conduction of the material, combined with its ability to entrap air within its structure. Textile structures are typically low in density and entrap more immobilised air within them than leather. A fine fibre network with high bulk and low density provides high levels of entrapped air. Typical low-density structures include fleece fabrics, non-woven fibre wadding, foams and feather-filled structures. Thermal resistance is reduced if material density is increased by crushing. Crushing expels entrapped air, reducing thermal resistance. Thermal resistance layers can be crushed if worn under a tight-fitting shell garment.

Thermal resistance may also be reduced if the air within a garment's structure is able to move. Airflow through a structure or through garment closures are the most common reasons for movement of entrapped air. Motorcycle clothing can be exposed to high-speed airflow into and over the material surface. This airflow can displace entrapped air, reducing thermal resistance. Wind-resistant barriers and efficient closures at the neck, waist and cuffs should be used to avoid forced air movement within a garment when it is designed for use in a cold environment.

For textile clothing, thermal resistance (R_{ct}) uses the same thermal guarded hotplate system as R_{et} in dry mode. The material to be tested is placed onto the hotplate in a controlled temperature and humidity environment. The energy required to maintain surface temperature of the hotplate is measured to calculate R_{ct}.

Thermal resistance is not measured as part of EN 17092:2020. MotoCAP measures R_{ct} with a thermal guarded hotplate following ISO 11092:2014 and uses this measurement, along with R_{et}, to provide a thermal comfort score and breathability rating. A range of different materials have been measured for thermal resistance and the results for these are given in table form in Appendix C.

3.4 Air permeability

Air permeability is important in garments as it allows airflow through them, improving breathability. Traditional motorcycle clothing materials such as leather have very poor air permeability. To enable airflow movement through leather, vents or perforations must be added to the garment, increasing its complexity and, in some cases, reducing its protection levels. Textiles can have high air permeability. The degree of openness of a textile structure will control the amount of airflow that can occur through a material. Woven fabrics normally have lower air permeability than knitted fabrics. Mesh fabrics provide the highest air permeability.

Selecting materials with higher air permeability can help when designing clothing for warm riding environments. Air permeability allows an effective release of moisture from within the garment while allowing fresh airflow to enter from outside the garment. Airflow into the garment is often increased at riding speeds, improving rider comfort when riding in warm to hot conditions. Protective denim jeans are one example of garments with high air permeability; these represent an increasing proportion of the market compared to traditional leather and textile pants. The air permeability benefits provided by the denim and protective fabric layers result in more comfortable riders in warm and hot weather both on and off the motorcycle.

Air permeability is measured by placing a material or combination of material layers onto a surface with a fixed-diameter orifice above and below. A controlled air pressure is then applied to the orifice and the volume of air passing through the fabric is measured. Air permeability is not measured as a part of certification under EN 17092:2022 nor assessment by MotoCAP. There is, however, a reasonable relationship between moisture vapour permeability and air permeability for garments suitable for use in hot weather. A range of different materials have been measured for air permeability and results for these are given in table form in Appendix C.

3.5 Resistance to water penetration

Water-repellent materials can reduce the risk of water penetration, whereas waterproof materials are much harder to penetrate. Water repellence can be achieved using a chemical coating on the surface of the clothing material; waterproofing will require a water-resistant membrane to be used in the construction of the garment.

3.5.1 Water-repellent coatings

Water-repellent coatings are achieved by increasing the surface energy of the outside of a material to make it hydrophobic. Super-hydrophobicity is desirable, as this provides a very high contact angle for water droplets on a surface, making it hard for fabrics to wet. The coating chemistry that can be used to achieve hydrophobicity includes fluorinated hydrocarbons, silicones, hydrocarbon waxes and oils. Water-repellent coatings perform poorly when pressure is applied to the water sitting on their surface. Sufficient pressure could be from rain droplets hitting the fabric during a heavy downpour, or from moisture on a motorcycle seat being compressed into a rider's pants during riding movement or when alighting.

Fluorinated coatings have been very popular as they can achieve a super-hydrophobic coating on most surfaces, along with oil repellence. They are easy and of low cost to apply, using a pad cure process. The coatings are very thin on the surface of the textile and often do not change the handle or drape of the fabric. Fluorinated coatings suffer from poor resistance to abrasion and are worn away over time due to usage and laundering, allowing wetting to reoccur.

The coating chemistry for these types of coatings uses perfluoroalkyl and polyfluoroalkyl substances (PFAS), which are likely to be banned or restricted in the future. This is because PFAS have been found to be persistent, bio-accumulative and toxic, especially in their long-chain form. This is the same chemical that has caused significant land contamination problems at airports, military bases, fuel refineries and firefighting training facilities due to its use in firefighting foams.

The number of alternative water-repellent coatings in the market has increased since 2010. These coatings are also applied by a pad cure process. The non-fluorinated water-repellent coatings do not offer as good water repellence as fluorinated coatings and do not offer oil repellence. This lower repellence should be considered as part of design when changing coating methods. The non-fluorinated coating may also influence drape and handle of the textile product. An example of this is paraffin wax coatings, which are well known in the motorcycle clothing space as waxed cotton. These coatings can give an oily handle to the cloth and can result in cross-contamination and staining of garments that contact them. Significant development is occurring in the non-fluorinated water repellence area, and new products should be evaluated as they emerge.

3.5.2 Waterproofing

Waterproofing is a term often used by manufacturers for a garment that contains a water-resistant membrane. In most cases, these membranes can transport water vapour through the membrane while excluding the transport of water droplets. This provides a breathable membrane that can allow moisture vapour to be released from the body out through the garment. Breathability of the membrane is an important component in the design of water-resistant garments to provide a comfortable climate within the garment. The type of membrane used, the fabrics it is used with and where it is placed in a fabric laminate will have a substantial effect on MVT. It is important to note that the MVT provided by the membrane manufacturer is normally for the membrane only. For accurate results, the whole garment fitted with the membrane should be measured. Above 10,000g/m^2.24hr is recommended as a good starting point.

Waterproofing is rated as the pressure of water that a fabric can resist before letting water droplets through. The measurement is reported in millimetres of water sitting on the fabric, with the higher the number, the better the waterproofing. Early testing methods clamped a fabric to the base of a column of water. Current methods clamp the fabric over a chamber and apply hydrostatic pressure with a hydraulic ram. Above 10,000mm of water resistance is a good minimum value to aim for when selecting garment materials. Waterproofing and breathability are often mutually exclusive, so it can be difficult to maximise both values.

Placement of the water-resistant layer within a garment influences its breathability. Laminating the water-resistant layer to the outer shell of the garment increases the breathability of the garment compared to a floating water-resistant layer; however, to be effective, lamination requires all seams to be sealed and the use of water-resistant closures (zips). Seam sealing reduces the area of breathable fabric, so minimising seams within a garment is important.

The alternative method of installing a water-resistant membrane is as a free-floating layer placed between the shell fabric and the inner liner fabric. This reduces the complexity of water-resistant closures and the need for seam sealing. However, free-floating layers have several drawbacks. They create an air-impermeable layer between the shell and wearer that stops vented air from getting to the rider's skin. The area between the fabric outer shell and the water-resistant layer can fill with water that penetrates the shell fabric but is then trapped in the void in between. This water may then wick through the fabrics in cuffs and waistbands, wetting the rider's undergarments.

4 Visibility and conspicuity

Conspicuity is the ability of an object to attract the attention of people who are not expecting or looking out for it.

Motorcyclists often assume that, if they are within the visual range of another vehicle, then the driver will see them. Unfortunately, other drivers are more likely to be looking for larger vehicles that represent a threat to them, whereas motorcycles are smaller, narrow objects that are easily overlooked in a complex traffic environment.

The majority of motorcycle crashes occur in daylight and involve other vehicles whose drivers have failed to see the motorcycle or misjudged the distance between them. The reality is that motorcyclists need to actively attract the attention of drivers and never assume any driver has seen them.

This chapter includes the following sections:

4.1 The differences in performance and application for fluorescent and retroreflective materials.

4.2 Key elements in the design of high-visibility clothing for daytime and night-time motorcycle clothing.

4.3 Theories and challenges of designing high-visibility and conspicuity into motorcycle clothing; this section provides further background to that given in Section 4.2.

4.1 High-visibility clothing

To be conspicuous, a motorcyclist must stand out against their background. High-visibility materials can make some objects substantially more conspicuous, but this varies according to lighting and the complexity of the road environment. Many factors contribute to conspicuity, including the object's luminance contrast, colour contrast, pattern and design, and motion against the background. In daylight, white clothing and helmets have been found to be detected more frequently on busy urban roads, while black was more distinctive in rural settings. Reflective yellow vests were less effective than either black or white clothing.

There are two main types of material used to increase visibility: fluorescent and retroreflective material.

Fluorescent materials are treated with pigments that absorb ultraviolet light from sunlight and convert it into visible spectrum radiation. Fluorescent colours appear brighter compared to standard dyes because they emit more light. However, fluorescent colours are only effective in daylight conditions because they do not respond to artificial light sources. A further major disadvantage of fluorescent materials is that the pigments fade and have a relatively short lifespan, which limits their usability in motorcyclists' clothing.

Retroreflective materials are covered with microscopic glass beads or prisms that bend and reflect light back to its source. Materials made with glass beads are cheaper to make and are brighter at close range than those with prisms, however prisms are visible over greater distances. Retroreflective materials are most effective at night or in low light when there are few other light sources. They are less effective in daylight due to the wide range of light sources that diffuse their reflection.

Retroreflective is not the same as reflective and the difference between them is important to their functionality. Whereas retroreflective directs the light directly back to its source, reflective materials are like a mirror and reflect light in the opposite direction to its angle of entry (Figure 4.1). This means they are less reliable as a means of identifying hazards in the path of the light source.

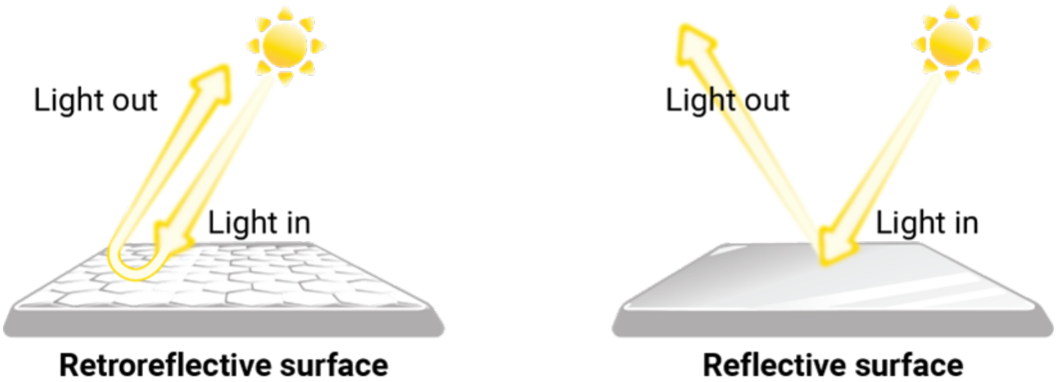


Figure 4.1: Retroreflective and reflective surfaces.

4.2 Designing high-visibility clothing for motorcyclists

There are no set guidelines or firm data on the design of motorcycle clothing to increase rider conspicuity. The following information can be used to improve daytime and night-time visibility during the design of motorcycle clothing.

4.2.1 Daytime conspicuity

Design for daytime conspicuity requires a garment that has an outline of the human body in one solid block of colour. A solid block of colour can help to distinguish the rider from backgrounds. Solid colours should be achieved as a minimum in the arms and legs of the garments, as this provides the outline of the rider’s body. Road users can recognise the outline of the body as being a person and this helps with the visual recognition of riders. The arms and legs are also less likely to be obscured by the motorcycle, fairings or backpacks.

Multiple colours and patterning should be avoided as these can allow a garment to blend into a background, obscuring the rider. Lighter colours such as white and fluorescent materials are the best solid colours to use for higher visual recognition. Dark block colours such as black and brown can work in some environments, such as rural roads.

4.2.2 Night-time conspicuity

The visibility of a motorcycle at night-time is easier to achieve than in daytime because the lights and reflectors on the vehicle play a greater part in its recognition. However, a rider's personal conspicuity is particularly important at night, because their clothing is often dark, increasing their risk of being struck by another motorist when approaching or leaving their motorcycle on the roadside.

Retroreflective materials can highlight a rider in a vehicle's headlights. Traditionally, large tapes of retroreflective materials have been placed onto riders' garments, as shown in Figure 4.2a. While these significantly improve the visibility of a rider at night, they can cause patterning and blending into a background during the day.

A wide range of retroreflective products is available to manufacturers, including threads, cords, films, coatings and thin tapes.

Retroreflective sewing threads

Sewing threads have been designed so that they have retroreflective elements in them. These can be incorporated in the seams of a garment as an additional decorative thread. The accent of reflective material on the garment helps to avoid patterning while still achieving night-time visibility. These can also be used to embroider patterns onto a garment that show up at night but are less noticeable during the day.

Retroreflective cords and thin tapes

Retroreflective cords and thin tapes can draw attention without the large patterning effects seen with thick tapes. These are best used at seams and cuffs to avoid patterning. This style of retroreflectivity often excludes a garment from meeting visibility standards for non-motorcycle clothing but can increase the night visibility of a rider.

Retroreflective coatings

Retroreflective coatings are a huge step forward in improving night-time visibility. These materials can be coated onto motorcycle clothing, with most being invisible under daylight conditions. This allows solid block colours for daytime visibility and high retroreflective effects during the night.

Retroreflective films

Stretch retroreflective films are coated directly onto a material in bands. They are black in colour under daylight conditions and highly reflective at night. Like retroreflective coatings, these can be used to enable block colours for daytime use and reflectivity at night. The first stretch retroreflective film in the market was 3M's Carbon Black.

4.3 Designing high-visibility clothing for motorcyclists

Many crashes between motorcycles and other vehicles are due to the other vehicle driver either failing to see an approaching motorcycle, or failing to allow a sufficient gap between their vehicle and the motorcycle. This type of crash is commonly labelled "SMIDSY" – "Sorry, Mate, I Didn't See You". There is evidence that motorcycles with features designed to increase conspicuity have a reduced risk of being involved in crashes with other vehicles. However, there is little information on the optimal design for motorcyclists' protective garments. Research to date has tended to focus on the design of conspicuity aids for pedestrians and cyclists rather than motorcyclists.

There are standards for high-visibility safety garments for many occupational contexts; however, none of them specifically reference motorcyclists. Those standards are based on designs to reflect characteristic movements of the limbs of a human body. A human figure can be recognised when walking in darkness solely from the movement of small lights attached to their limbs. Designs based on a moving human body effectively identify pedestrians and cyclists, but are less likely to be effective for motorcyclists due to the stationary position of the limbs while riding. The most recent standards are Australian Standard AS/NZS 4602.1-2011, Amendment 2:2020, and two European standards: ISO 20471-2013+A1:2016 and EN 17353:2020, for high- and medium-risk situations respectively.

There has been some research into the optimal hi-vis design for pedestrians that suggests placing a greater emphasis on illustrating the overall shape of the human body; this may increase detection when the wearer is stationary. Figure 4.2a represents the application of reflective materials specified in the original European Standard for high-visibility garments (EN 471); Figure 4.2b illustrates Biomotion design, which highlights the major joints; and Figure 4.2c, Stickman, is an example of a whole-body outline.

The Biomotion and Stickman designs were found to be more effective than the high-visibility standard for the detection of pedestrians and cyclists moving in dark conditions, whereas when the wearer is stationery Stickman was more effective than either Biomotion or the Standard EN 471. Although there is little research specifically in relation to motorcyclists, it does appear that the application of reflective strips to highlight the shape of a motorcyclist in riding position from front, side and back may optimise their detection in traffic.

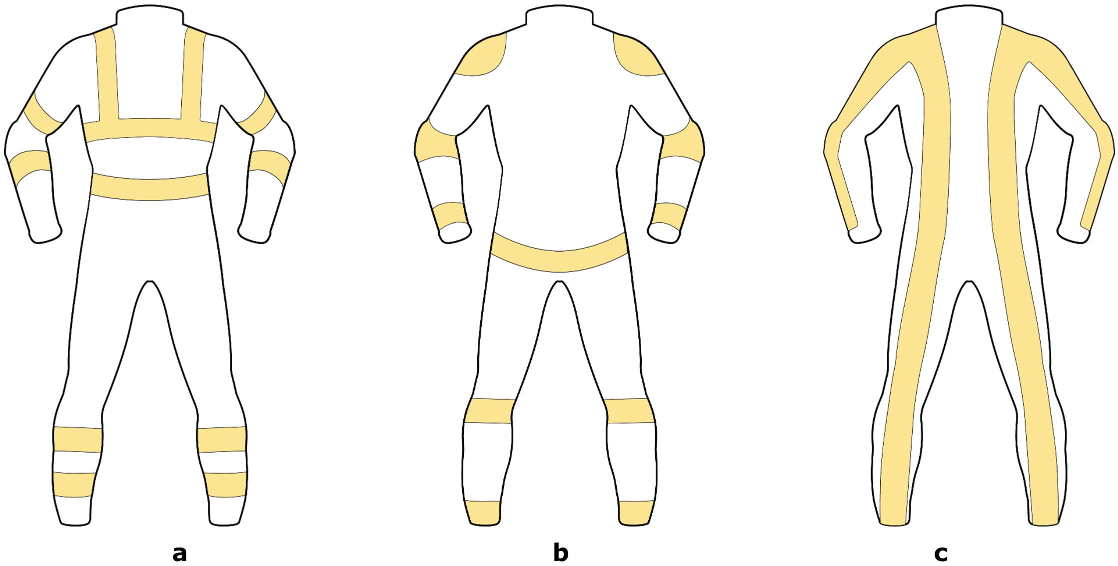


Figure 4.2: Graphical representations of high-vis design for (a) EN 471, (b) Biomotion, and (c) Stickman.

Motorcyclists' conspicuity is also a more complex problem than for bicyclists or pedestrians. This is not only due to the lack of motion by the motorcyclist's limbs but to the different features of motorcycles such as fairings and windscreens, or riding positions that may block a driver's view.

The fairings on some motorcycles, such as cruiser and touring motorcycles, can obscure the rider's clothing. Figure 4.3 shows how the presence of a backpack can obscure parts of the rider's back. The orange vest of the rider is harder to observe for the rider from behind. Further work is required to determine the optimal means of enhancing the conspicuity of a rider's clothing compared to that of the motorcycle.

Figure 4.3: The blocking of riders' high visibility clothing by a backpack.

5 Elements of garment construction

Seams and fastenings are a critical issue for motorcycle clothing manufacturers. The location and construction of seams and fastenings are as essential to the overall protective performance of motorcyclists' clothing in a crash, as is the choice of materials. Linings and impact protectors are also important aspects of garment design and construction.

This chapter includes the following sections:

5.1 Factors determining seam strength, including seam types, stitch count and length, thread types and needle selection.

5.2 Types and selection of fasteners, including zips, hook-and-loop fasteners, buckles, buttons and press fasteners.

5.3 Test methods for evaluating fasteners.

5.4 Selection of lining materials, and their placement and construction.

5.5 Different types of impact protectors and their optimal placement in a garment.

5.1 Seam strength

There is an almost limitless number of different seam constructions and configurations. Seams can fulfil either structural requirements or cosmetic functions. In this guide, we illustrate a few main examples of commonly used structural seams to establish the principles of suitable and sufficient construction.

This section describes the factors which, individually and/or cumulatively, contribute to seam strength:

1. seam types (main structural seams, decorative seams and lining seams)
2. needle selection
3. thread selection
4. stitch count
5. thread tension.

5.1.1 Seam types

Main structural seams

In those areas of motorcyclists' clothing where the risk of contact with the road surface is highest (Zones 1, 2 and 3 as defined by EN 13595 and MotoCAP; Zones 1 and 2 as defined by EN 17092), it is essential that at least one line of stitching is protected by a layer of a structurally strong material, as shown in Figure 5.1. This can be achieved either by folding or covering the seam with an additional layer of material (e.g. a continuous strip). This technique should also be applied in lower impact-risk areas (Zone 4 as defined by EN 13595 and MotoCAP; Zone 3 as defined by EN 17092), but avoided in areas, such as behind the knees, where the additional bulk of material may cause discomfort. See Figure 2.1 for the four-zone impact risk model (EN 13595).

A lock stitch is the most secure option for motorcyclists' clothing, because it ensures most of the seam will remain intact and not unravel, even if a section of thread is abraded or cut. Chain stitches have traditionally been avoided in motorcyclists' clothing, because they can unravel if abraded or cut, causing the seam to split open in a crash and potentially exposing the wearer to injury.

As elasticated textiles become more prevalent, the use of chain stitching may be necessary because the inherent stretch in this type of stitch is more suited to the flexibility of the materials. Chain stitching may also reduce the risk of stresses being placed on a seam that may occur if a lock stitch was to be used with stretchy materials. In such cases, consideration should be given to using chain stitching in combination with concealed lock stitches to achieve a balance of flexibility and security.

Decorative seams

Decorative seams are used to attach non-structural features to a motorcycling garment, such as additional layers of material external to the main structure of the garment in the form of stripes, logos or badges. These elements are generally sewn around their periphery with a single row of stitching. The same considerations of needle type, thread specification, stitch count and thread tension (see Sections 5.1.2–5.1.5) need to be exercised with decorative seams as with structural seams, so that the underlying structure of the garment is not compromised.

Assessments of embroidered logos suggest that when these are used with appropriately strong materials, and in the areas at lower risk of impact and abrasion, they do not necessarily reduce the tear strength of the construction to an unacceptable extent. However, this should always be assessed and verified by testing on a case-by-case basis.

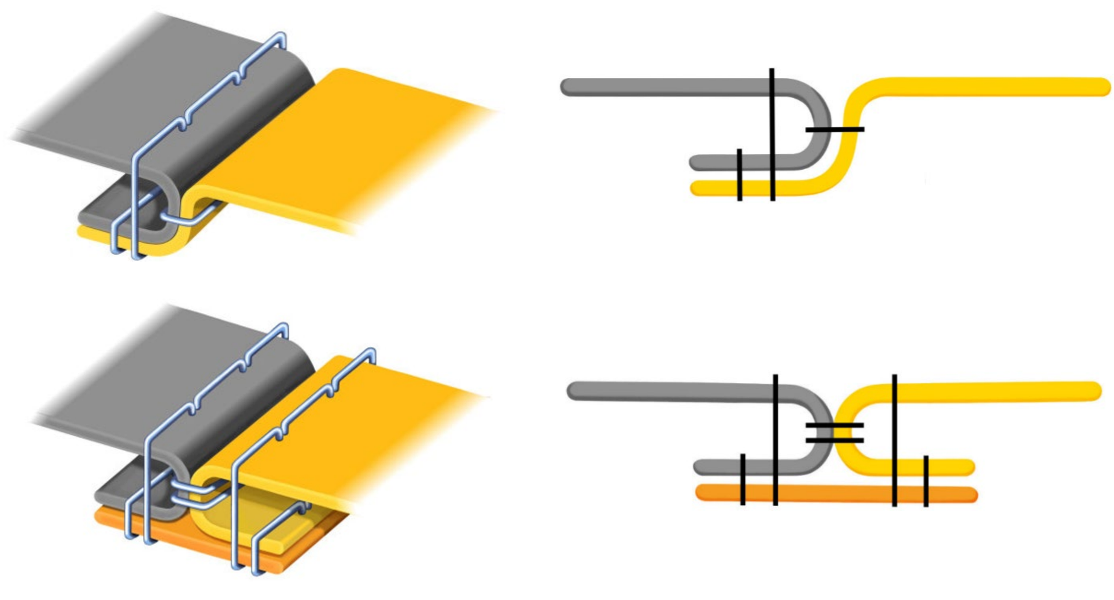


Figure 5.1: Typical examples of suitable outer-layer seam constructions.
Images: Supplied by BKS (Made to Measure) Limited, UK

Lining seams

Lining seams are commonly overlocked, although they can also be sewn using a single row of stitching.

Linings perform a key role in mitigating certain types of soft-tissue injuries, such as skin shear injuries. It is essential that they are sufficiently robust to remain intact when the garment impacts with and slides along the road surface, as well as during normal wear – preferably for the service life of the garment.

5.1.2 Needle selection

Needle type

Two main types of needles are used in the manufacture of motorcycle protective clothing:

- cutting point, for leather and sheet materials such as rubber
- round point, for textiles.

Cutting point needles create a hole through which the thread passes, whereas round point needles slide between the fibres of woven or knitted textiles with minimal snagging or damage. The use of an incorrect needle can weaken the material structure, which has a direct effect on tear, burst and impact abrasion resistance of the seam and garment.

Needle finishes

Needles may also have finishes or coatings for specific purposes and tasks. For example, needles designed for sewing with elasticated materials or threads often have a higher eye and flatter scarf (i.e. indentation above the eye).

Coatings may also be applied to reduce friction between the needle and the material being sewn. Friction can be the cause of thread breakages, weakening seam strength and increasing manufacturing times. Low-friction needles are also essential when working with textiles that have low melting points.

Needle size

The size of the needle is determined by taking account of the thickness and weight of the materials, the thread to be used and the intended stitch count. A smaller needle is required for materials with a fine knit or weave structure.

5.1.3 Thread selection

The type and weight of thread should be determined by the weight and tear strength of the materials to be sewn.

The tear strength of the material, identified through testing, will provide an indication of the weight of thread to be used, and should then be verified by burst or tensile testing samples of the materials in the proposed seam constructions. Mismatches occur when materials with high tear strength are sewn with weaker threads, or materials with low tear strength are sewn with stronger threads. In each case the seam will fail either due to the thread breaking or the material tearing along the stitch line. Testing is essential to establish the optimal combination of materials and threads.

Commonly used thread types are polyamide, polyester, polyester-cotton blend and aramid. Note that aramid threads should only be used to stitch aramid fabrics because, due to their high tear strength, their use with other textiles or leather may result in the thread tearing through the material. This is a particular risk with gloves because the aramid thread may act like a "cheese wire" and cause severe injuries to the wearer's hands and fingers.

5.1.4 Stitch count

Stitch count (or stitch density) is the number of stitch holes over a specified distance of the seam, commonly measured in stitches per inch.

A lower stitch count (i.e. longer stitches) may be appropriate for heavy-duty materials that are sewn with a heavy thread. Conversely a higher stitch count (shorter stitches) may work better when joining lighter textile sections.

High stitch counts should be avoided in the main structural seams of leather garments because they can significantly reduce the material's resistance to tearing along the seam line. Such seams can rip open under pressure, leading to catastrophic structural failure of the seam and the consequent risk of injury to the wearer.

Seams with any exposed stitching are at risk of being pulled open if the top stitching is abraded in a slide along the road surface. A low stitch count increases the risk of such seams being compromised, whereas a higher stitch count might result in more of the stitches surviving to retain the strength of the seam. A hidden line of stitching in these locations reduces the chance of abrasion-induced failure of a seam.

Typically, stitch counts of 6 to 8 per inch are employed in the seaming of leather garments, and 8 to 10 stitches per inch in textile garments. These values are only indicative, however, and vary widely among the many different materials available, the combinations of materials, and seam designs. It is essential for manufacturers to conduct appropriate testing to identify the stitch counts that work best for their materials and seam constructions.

5.1.5 Thread tension

Thread tension is controlled by sewing machine setting.

The thread should rest slightly into the material and not stand proud of the surface. This is to prevent thread from catching on rough surfaces in high-impact contacts, and is more easily achievable with thicker leather than with thinner leather and most textiles.

While the garment might brush past rough surfaces in normal wear, crash conditions are very different. In a crash, the garment is forced against the surface under the full weight of the rider on impact and as they slide, increasing the risk of abrasion damage to the material and exposed stitching.

If stitch tension is too tight, it will put strain on the thread where the needle thread loops through the bobbin thread, which can initiate earlier stress failures. This can also lead to placing pressure on the edges of the stitch holes and tearing of the fabric.

If thread tension is too loose, it will allow the loops of thread between stitch holes to stand proud of the surface of the garment, rendering them more susceptible to abrasion by the road surface. This also increases the risk of damage in normal use, for example when brushing past coarse surfaces such as stone and brick walls.

5.1.6 Optimising seam strength

These five factors – seam type, needle selection, thread selection, stitch count and thread tension – contribute both individually and cumulatively to overall seam strength. If any of them are out of sync with the component materials, the seams may fail despite the materials being realistically capable of much higher performance had the optimal seam design been used.

Manufacturers are strongly advised to "know their materials" and "know their constructions" by obtaining and cataloguing data from test reports on their products. This information can be built into a database that will inform future decisions about product design. Where regulatory processes require testing and verification of products, the assembled data may help to avoid duplicating the costs of testing, and to streamline the process to provide faster completions.

5.2 Fasteners

The most common types of fasteners in use in motorcyclists' clothing are:

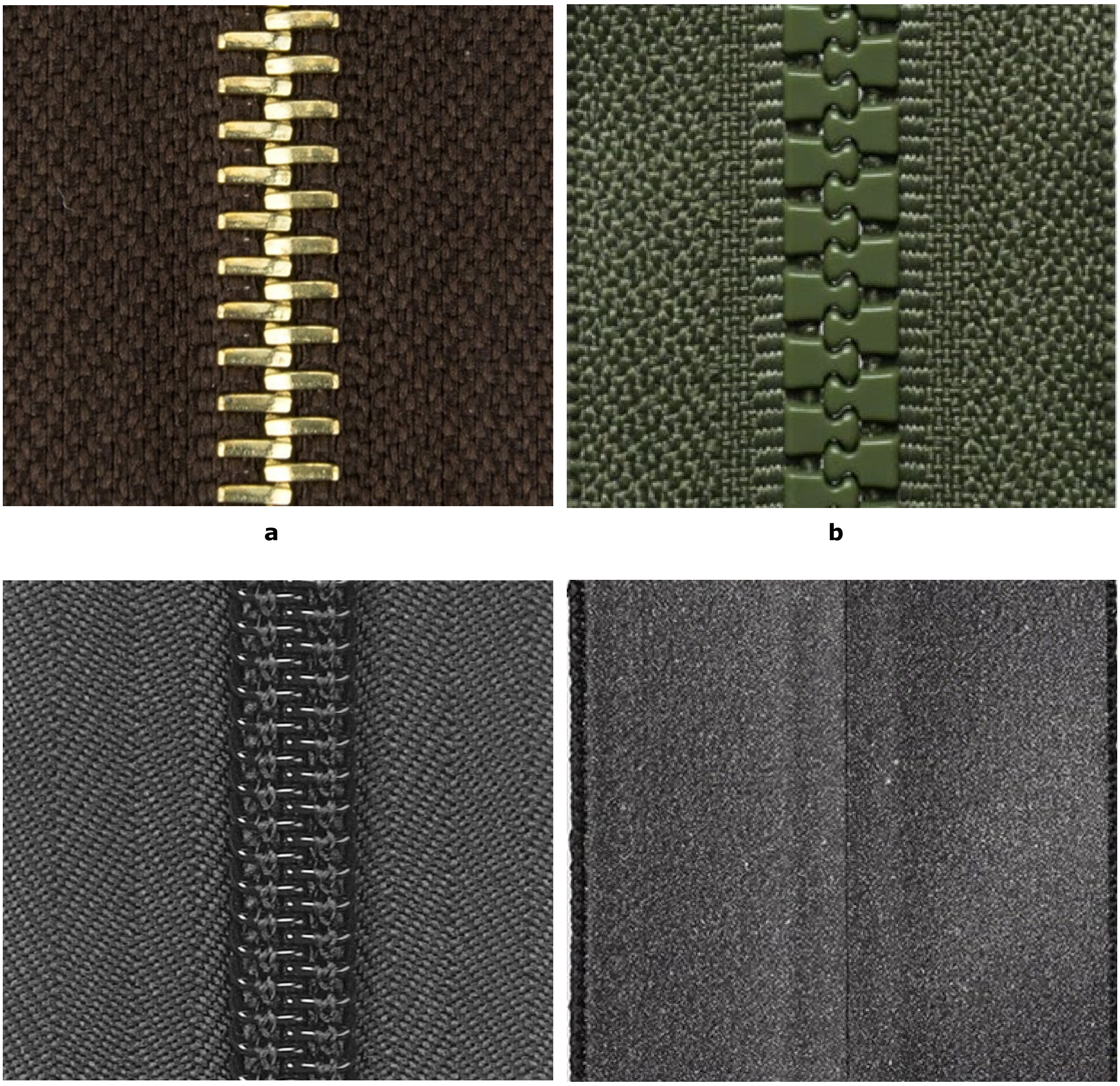
- zip fasteners
- hook-and-loop fasteners (e.g. Velcro)
- snap-fasteners and buttons
- buckles.

5.2.1 Zip fasteners

Zip fasteners are the primary method for securing the main closures of motorcyclists' clothing: the front zips of suits and jackets, the fly zips of trousers, wrist and ankle cuffs, gloves and many styles of footwear. There are a number of factors to consider when deciding on the type of zip fastener to be used, although style and convenience will also play a part.

There are four main types of zippers detailed below and shown in Figure 5.2:

- metal (with fabric backing tape)
- plastic moulded (e.g. Vislon™)
- coil
- water-resistant.



a b c d

Figure 5.2: Zip types: (a) metal teeth, (b) plastic moulded, (c) coil, and (d) water-resistant.

Coil zippers have been found to outperform metal and plastic moulded zips in terms of ease of operation, robustness, resistance to separation and reliability. Test data has found that a 5W coil zipper (i.e. 5 weight) will outperform 8W plastic moulded zippers and even heavier metal zips.

The coil zipper is formed from a single coiled monofilament, which provides a significantly greater area of contact between the teeth than occurs with the individual teeth of metal and plastic moulded zips. Coil zippers are also more flexible and suitable for motorcycling apparel where the zip fastener is required to follow the contours of the body when the wearer is seated on a motorcycle, such as in the abdomen of suits and in trousers.

There has been a growth in the use of water-resistant zips, especially in textile garments that are intended to be worn in all weathers. These are manufactured using the plastic moulded or coil zips with a water-resistant coating on one of their sides. Coatings are normally a polymer such as polyurethane. When the zip is in a closed position, the inner edges of the coating are held close together to form the seal that restricts water entry.

Snagging of garment liners in zips is a common problem with motorcycle clothing; it increases the difficulty in donning and doffing garments. Snagging can be avoided by changing the design of the textile edges of the zip to exclude the liner from the slider openings, or by adding an anti-snagging slider cover such as those made by YKK.

The European standards for motorcyclists' clothing, gloves and footwear, and the requirements of MotoCAP, each set minimum performance criteria to consider when choosing a zip fastener type. Testing of zip fasteners is discussed further in Section 5.3.

5.2.2 Hook-and-loop fasteners

Hook-and-loop (or hook-and-eye) fasteners such as Velcro are not recommended as the main closure mechanism for a motorcyclist's garment because they are unlikely to have sufficient strength to resist crash forces. They may be used as part of a secondary method to protect zip fasteners from opening inadvertently, such as fastenings for:

- material tabs covering the end of the zippers at the collar or wrist cuff
- storm flaps over the main front zip fastener on jackets
- adjustment at the collar, wrist cuffs and waistbands of jackets or pants, sometimes in combination with a buckle.
- the location and adjustment of impact protectors (see Section 5.5).

5.2.3 Snap-fasteners and buttons

Snap and button fastenings are also not recommended for use as a primary mechanism for closure. As with hook-and-loop fasteners, they should only be used as secondary fastenings to protect the primary closure mechanism (zipper) at the collar, cuff or waistband, or on a storm flap.

5.2.4 Buckles

Buckles come in a range of shapes and sizes. The main types of buckles are tongue, plate, clip, double ring, friction and box (Figure 5.3). Traditionally, buckles were made from metal and have a prong that is mounted to a bar and frame that is passed through an eyelet in a belt. Clip and friction buckles are becoming more common especially for the arms of jackets to restrict impact protector movement. As plastic buckles become more common it is important that the structural strength of the buckle be suitable for the application.

Figure 5.3: Buckle types.

Structurally sound buckles have a strong closure method and a locking action that make them suitable for fastening pants and jackets at the waist. They may also be used to restrict the movement of impact protectors. Buckles should be avoided at the neck and wrists of a garment as they are difficult to operate in these locations.

Tongue buckles should have a strap loop to retain the loose end and avoid it slipping on the prong during a crash. The strap loop is better when it is provided by part of the metal frame rather than a separate sewn loop on the belt.

Double ring, friction and box buckles should be avoided as closures in high-risk areas as they are prone to slippage, especially with aging of their strap. Large buckles or those with a high profile should be avoided due to the risk of them being forced into the body during a crash (see Section 2.9.5).

5.3 Durability of zips and fasteners

Zips and fasteners often provide important structural integrity to a garment – in closures at the arms, legs, chest and crotch, and in vents. Failure of one of these closures could result in exposure of the wearer's body to the road or other objects during a crash. Testing can be conducted using AS 2332 with "medium" class zips or those of a higher quality suitable for use in motorcycle protective garments. Most companies will provide testing results for their closures if requested.

Buckles and straps can be evaluated using tensile loading to failure. Both buckle and strap should be tested together to ensure they work well as a unit. This is important when testing friction buckles. Avoid the use of closures that have not been tested in any critical locations for injury protection.

The European motorcycle clothing standard EN 17092 utilises the tensile test method for measuring zips and fasteners, as detailed in EN 13594:2015 Annex B. Standard EN 13595 and MotoCAP both assess the strength of zips and fasteners using EN 13595-3:2002.

5.4 Linings

Lining materials perform vital roles by:

- reducing the risk of skin shear injuries when sliding along the road surface
- providing pockets for separate impact-protection components (see Section 5.5)
- enabling garments to be donned and doffed over normal clothing more easily.

Linings must encase the rider in fabric that has a low surface coefficient of friction (i.e. fabric that is slippery). This will reduce the risk of skin shear and friction burns by separating the rider from the forces transferred through the outer shell of the garment as it slides over the road surface. It is essential that the slippery side of the material is placed against the inside of the outer shell material, with the less-slippery side against the wearer's skin.

Polyester mesh linings are most commonly used for liners due to their low coefficient of friction, low price and durability. Other materials, including silk, viscose/Lyocell/Tencel™, and mercerised cotton liners, can provide linings with similarly low coefficients of friction. Mesh liners allow better airflow and rider comfort, especially in summer garments. Fabrics can be used instead of mesh, with satin, sateen and some knitted structures giving the desired low-grip surface characteristics required of a liner.

The increased availability of single-layer riding jeans and casual garments without the slippery inner liner is a concern for rider injury risk. This is because, even with a highly abrasion-resistant shell, a slippery inner liner is still necessary to reduce the risk of skin shear and friction burns transferred when in direct contact with the inside of the outer fabric.

In the absence of a lining, a base-layer garment (e.g. long sleeved T-shirt and leggings) of suitable material composition may also mitigate skin shear injuries.

5.5 Installation of impact protection

Impact protectors must cover all Zone 1 areas and remain in place in the event of a fall from the motorcycle. Impact protectors come in two sizes specified by EN 1621-1:2012, and different shapes according to the part of the body to be protected. It is essential that the correct type and size is installed for each Zone 1 area. The type and size must be permanently labelled on the protector, together with its CE certification (refer to Section 2.9 for details).

The most effective means of installation is via pockets within or attached to the lining, provided that the pockets are designed to allow the protectors to be replaced as necessary. The impact protector is placed into the pocket, which is then closed and secured by a hook-and-loop fastener/Velcro or by design technique. It is important for the protectors to be held strongly in place within the pocket, and for the pockets to be held in place over the body joint, either by the use of Velcro or another low-profile fastener within the pocket structure.

Particular attention needs to be applied to the size and location of pockets for the elbows and knees due to variations in the relative location of those joints within the garment on taller or shorter riders, even when riders are wearing the same overall garment size.

Some manufacturers have designed garments to address this issue by providing systems for riders to adjust the lengths of the elbow- and knee-protector pockets. This system enables fine adjustment of the location of the impact protectors up and down – and, to an extent determined by the width of the fastener used, side to side. Once in place and adjusted for optimal comfort, the protectors will not shift position and only need to be removed when, for example, the garments require laundering or repair.

When using Velcro fasteners on linings and internal parts of a garment, care should be taken to avoid the hook part of the Velcro contacting the skin. This part is very stiff and can feel uncomfortable on the wearer's skin.

6 Sizing, labelling and ergonomics

Garment sizing, ergonomics and labelling are all intertwined, as garment must be sized and fitted correctly, in addition to meeting ergonomic requirements and detailed with the correct labelling. This chapter includes the following sections:

6.1 Internal labelling and swing tags.

6.2 How to define and communicate sizing to a purchaser, and the additional labelling required by European Standard EN 17092.

6.3 Fit and ergonomics, and the minimum ergonomic requirements a garment should have.

6.1 Labelling

6.1.1 Internal labels

Internal labelling is important as it must provide the user with the appropriate information to select, care for and use the garment, meet labelling laws for the country of use and not irritate the wearer's body. The internal labelling should meet all compliance requirements of the country of sale, even in the absence of swing tags. Labelling is traditionally done using jacquard woven fabric tags in two colours that are sewn into the seams of a garment. These labels are highly durable, both for colour fastness and structural integrity; however, they can cause skin irritation for some wearers. The use of labels printed directly onto the inner label of the garment can make garments simpler for recycling and reduce skin-contact irritation.

Placement of internal labels is important. The garment's size label should be easily accessed and large enough to be read by a prospective purchaser. Other labels – including brand, care and compliance – should be placed so that they do not irritate the wearer's body. If an inner liner is used, then the care label can be sewn into a seam of the inner liner and then tucked through a hole in the liner so that it is between the shell and the liner but can be readily accessed if required. This removes the label from direct skin contact.

The elements detailed in the code of conduct for display as an internal label are:

- size of the garment
- care instructions
- composition of materials
- country of origin.

Details of the labelling requirements for different countries can be found by searching the country's standards libraries. The labelling standards relevant in Australia are AS/NZS 4501.2:2006 for men's garments. The standard for women's garments (AS 1344) was withdrawn in 2009 and at time of writing has not been replaced. It should only be used as advice, since women's sizes have changed over time. In the absence of a unified system, most manufacturers set their own sizes.

6.1.2 Care labels

Care labels provide information as to how the garment should be laundered and dried to avoid fading or shrinking. AS/NZS 1957 can be referred to for details on how to set out care labels. The details that are provided on the care label should consider the materials the garment is made from. Motorcycle garments are regularly made from multiple materials that have conflicting care requirements. An example is a pair of chino pants reinforced with a para-aramid lining fabric. The cotton chino fabric may be able to withstand the presence of a bleach; however, the para-aramid fabric will be reduced in strength if exposed to bleach. In this case, the care label should specify that bleach should not be used during laundering.

6.1.3 Swing tags

Swing tags can be useful in providing additional space to describe the attributes of the garments. There are currently no restrictions on the size or shape of swing tags, although considerations should be given to the environmental load of the garment and publicity materials. Information of value to potential purchasers that could be included on a swing tag includes:

- size
- materials
- details of the protective elements
- types and locations of impact protection
- water resistance
- certification
- MotoCAP rating.

Unsubstantiated and irrelevant claims involving protection should be avoided, such as “High abrasion resistance in shoulders” or “Stronger than steel”.

6.1.4 Labelling requirements under EN 17092

Additional internal labels are required for garments certified to EN 17092-1:2020. Internal garment labels should ideally be situated in a position within the garment where they can easily be seen. Details are given within the standard. These are, in summary:

1. There must be a label that includes the EN motorcycle rider pictogram, certification level, standard number, make/model details, and manufacturer’s name and address.
2. There must be a second label that details the appropriate size of the rider for the protective elements of the garment to be effective. Details on specifying sizing is given in EN ISO 13688:2013, Protective clothing – General requirements.
3. A booklet must be provided with the garment, covering in detail the full use of the garment. There must also be a booklet for each type of impact protector present in the garment that is certified to EN 1621-1:2012.
4. Finally, manufacturers of EN 17092–conforming garments (as well as gloves, footwear and impact protectors conforming to their respective standards) must supply a copy of the Declaration of Conformity. This may be supplied with the product or available via a web

address that must be listed in the user information booklet. The Declaration of Conformity must include information such as the certificate number for the product and the name of the organisation that issued it. This is to enable consumers or authorities to check the legitimacy of a product's certification.

6.2 Sizing

6.2.1 Garment sizing

Sizing is critical for motorcycle protective clothing. Appropriate sizing means that a rider gets a garment that fits their body size and shape, ensuring that its protective features will stay in place in a crash.

As standards for body sizes vary across the world, the simplest way to provide size information in an international market is to provide the size of the rider for whom a garment is suitable. This is often done with a pictogram combined with two or more body-size measurements. Figure 6.1 shows the key measurements for males and females defined by EN 13402; these are a good starting point for specifying appropriate garment sizes. In the European Standard EN 17092:2020, a pictogram complying to EN 13402 is required to define the appropriate size of the wearer.

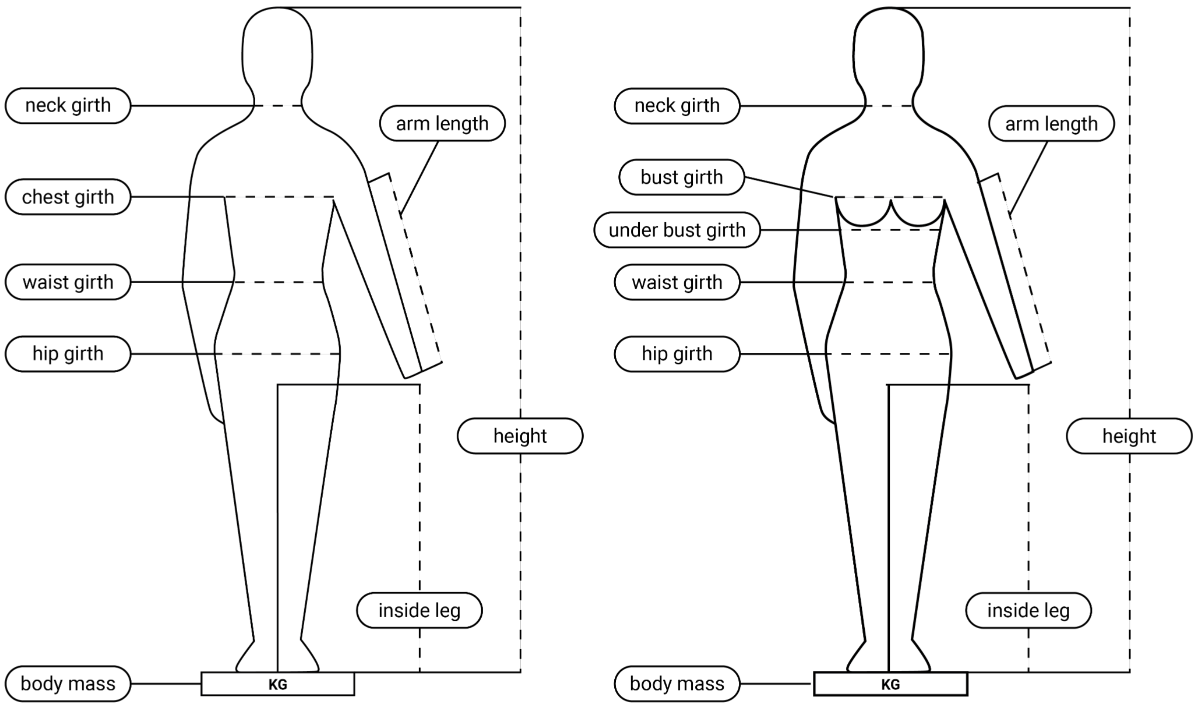


Figure 6.1: Pictogram for male (left) and female (right) body forms, with locations of key measurements.

For jackets, best practice is to give a rider's height and chest measurements. For pants, it is best to provide the rider's height and waist measurements; however, it is also common to give the inside-leg length. Garments for female riders often require additional information, including bust and hip girth.

6.3 Fit and ergonomics

For a garment to be suitable for use on a motorcycle, it should not restrict the rider when mounting, dismounting or operating the machine. The protective elements should be placed and held in the appropriate areas of the body to ensure risk reduction. Garments should be comfortable to wear for extended periods of time. However, comfort is a subjective measurement, with each individual having a different perception of what is comfortable. For example, one rider might like loose, open jackets, while another may like the feeling of a close-fitting jacket.

6.3.1 Variations in body shape and size

Fit and ergonomics are also complicated by the variation in the size and shape of the human body. Variations in body shape can result in protective elements moving away from their correct locations, leaving a part of the body exposed to a higher risk than it should be. These variations can be compensated for in garment design. Increasing the area of coverage of higher abrasion-resistant materials ensures critical parts of the body are protected for a wider range of body shapes. Retention systems for impact protectors can also be designed to enable movement and positioning. A manufacturer should also undertake ergonomics testing using a range of body sizes to ensure that protective elements are appropriately placed for all users.

The images in Figure 6.2 show just some of the body shape differences that can occur, without factoring in differences in height.

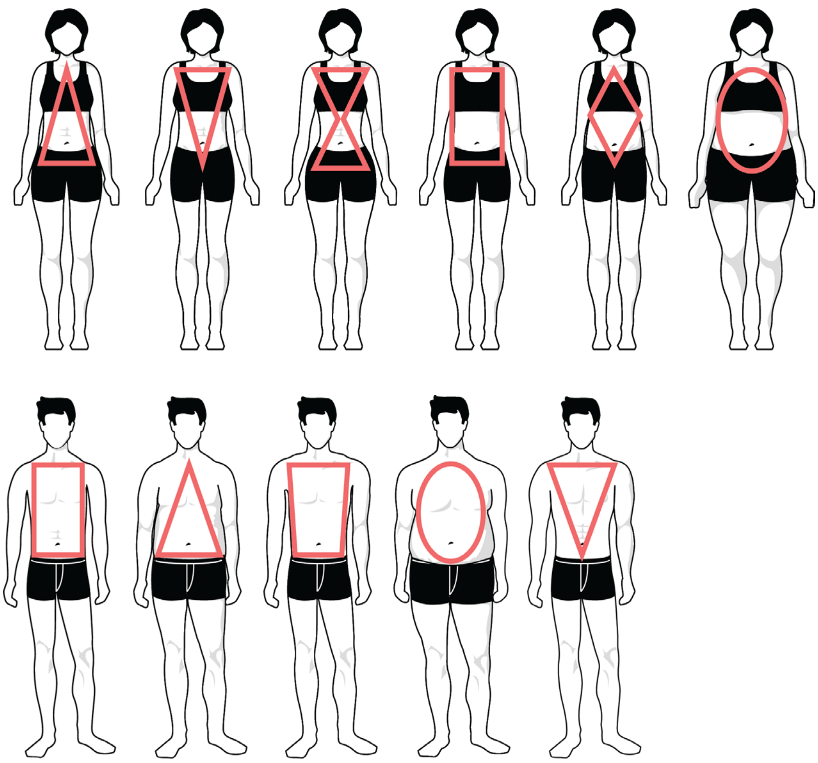


Figure 6.2: Some variations in female and male body shapes.

6.3.2 Ergonomics

Ergonomics testing is conducted to ensure that the garment is fit for purpose. As mentioned above, ergonomics can be affected by the wearer's shape or size, so it is important that the garment/s and wearer/s selected for ergonomics testing are appropriately sized. It is also important that the wearer has experience in riding a motorcycle.

Motorcycle protective garments are usually worn with other motorcycle garments and gear adjacent to them; for example, a jacket will likely have a pair of pants, a pair of gloves and a helmet adjacent to them. The wearer should be wearing each of these items when doing ergonomics testing. In this example, the interaction of the glove with the cuff of the sleeve may induce discomfort that is not present without the glove on. Similarly, a motorcycle or a frame shaped like a motorcycle should be used to ensure that the garment is fit for purpose in a riding position.

Ergonomics testing is normally broken down into several components: pre-donning assessment, donning, doffing, off-motorcycle activities and on-motorcycle activities. Where possible, the gear should be worn for some period and used on a motorcycle where there is wind movement up to rural speed limits. Use in a moving airstream can identify excessive wind entry and flapping elements.

Pre-donning

In this stage of testing, the garment is inspected for sharp items or elements that could cause harm in the event of a crash. These are hard elements that could penetrate the body or metal elements that could transfer heat through to the skin.

The garment is checked for compliance requirements including sizing, labelling, linings, impact protection and retention devices. The impact protectors are inspected to ensure they are adequately restrained.

Donning and doffing

The donning and doffing process checks to see that the wearer can operate all the fasteners easily; that there are no areas of discomfort or irritation due to materials, construction or embellishments; and that the adjacent garments and gear can be donned and removed easily while the garment is worn. Some activities may need to be done while wearing motorcycle gloves as they would be done while riding.

Once the garment is on the rider, the placement of the impact protectors is assessed to ensure correct positioning. If the garment allows adjustment of impact protectors, these adjustments can be made.

Off-motorcycle activities

The off-motorcycle activities assess the wearer's ability to undertake tasks without difficulty or discomfort, including walking on flat ground, climbing stairs, bending over, squatting down and mounting/dismounting from a motorcycle.

On-motorcycle activities

On-motorcycle activities assess a garment's suitability for use while sitting on a motorcycle. These include assessing that, without difficulty or discomfort, the wearer can sit astride a motorcycle seat and make hand signals, steering inputs, ground-to-foot-peg leg movements, gear changes and head checks. These checks include ensuring that the riding position does not result in the garment's unnecessary tightness; interfere with the helmet, gloves or boots; or alter the correct positioning of protective elements, including impact protectors.

In some cases, a garment will work adequately on the motorcycle but hinder the wearer's comfort and walking ability off the motorcycle. This is acceptable in garments that are designed for sports or track use, but is less suitable for a garment that is designed to be worn both on and off the motorcycle.

7 Durability

Durability is the measure of a product's ongoing performance during use. Components that affect a garment's appearance and size over time are measured in a range of tests. Most of these components have little effect on the protective performance of the garment, but may relate to its useful lifespan and influence the wearer's level of satisfaction with the product.

This chapter details the different durability tests that are recommended for motorcycle clothing and materials and can be read alongside the fabric and garment specification sheets provided in Chapter 8. The chapter includes the following sections:

7.1 Colour fastness issues in materials.

7.2 Innocuousness in motorcycle clothing, including the problems that can occur from dyes and chemical finishes, plus information about certification schemes and tests.

7.3 Dimensional stability in garments, and the changes to shape with laundering.

7.1 Colour fastness

Poor colour fastness can create two issues. One is the change in the colour of materials over time that may spoil the appearance of the garment; the other is the staining of adjacent garments or skin by colour that's lost from the garment. Colour change is normally more obvious in lighter shades, whereas staining is normally worse from deeper or darker dyed products. Staining tends to be the key problem with motorcycle clothing, as many garment styles involve deep and dark colours.

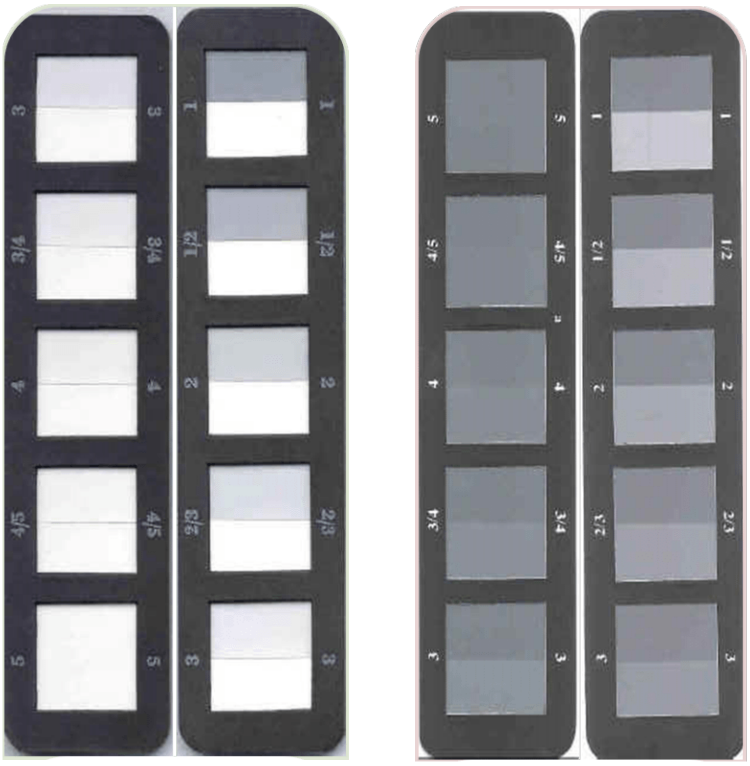
There is a range of different colour-fastness tests that apply to motorcycle clothing. Most of the tests are relevant even if a garment is not going to be laundered as part of its use.

The correct selection and application of dyes during the fabric's manufacture is critical in achieving good colour fastness. Motorcycle clothing manufacturers often have little or no control over the dyeing process, so it is important to set realistic and achievable colour-fastness specifications for products. As a minimum, manufacturers should require test results for all materials for rub, water and perspiration fastness. Light fastness should be included for lighter shades and wash fastness added for garments that may be laundered during use.

Fastness will vary depending on the product. For example, achieving a 4/5 staining rating for wash fastness on a black polyester fabric is relatively easy; obtaining the same result on a similar coloured leather is difficult. These differences are due to the dyes available to the dyer based for a particular fibre composition.

Colouration of materials is often done with more than one dye. Trichromatic mixtures of red, yellow and blue dyes are normally used to achieve a set colour. Poor fastness of just one of these dyes can have a significant effect on the colour of a garment over time. An example would be a beige garment where the blue dye from the trichromat has poor light fastness. Over time, the parts of the garment exposed to higher levels of light will change colour from beige to pink as the blue dye is degraded.

Colour fastness is evaluated using the ISO 105-A02 and A03 grey scale systems. There are two grey scales. One is used to determine the degree of staining that has occurred to an adjacent fabric (Figure 7.1a), and the other is used to determine the level of shade change that has occurred from before and after colour-fastness testing (Figure 7.1b). Both systems are graded from 1 to 5, with half-increments between each scale. A result of 5 is considered to have no staining or shade change, whereas a result of 1 is considered to have high levels of staining or shade change.



a **b**

Figure 7.1: Grey scale system for (a) degree of staining, and (b) shade change.

7.1.1 Rub fastness

Rub fastness, sometimes referred to as crocking, is the measure of colour transfer from one clothing material to another in use. It simulates the transfer of colour from an outer garment to an inner garment or vice versa. Rub fastness is important in order to avoid staining of adjacent garments. Darker dyed fabrics are more prone to have rub fastness issues than lighter shades, and deeply coloured leathers are more prone to transfer their colour than most other motorcycle clothing materials. Using mesh liner fabrics that have a high rub fastness within leather garments can remove the problem by isolating the inner surface of a leather shell.

An example of a rub fastness issue would be a burgundy dyed leather jacket worn over a white long-sleeve T-shirt, where the action of rider movement during riding causes the jacket to rub on the shirt from the shoulders to the wrist. The red dye from the surface of the jacket could transfer onto the white shirt, unevenly staining it pink in places.

Rub fastness is measured using a crockmeter. A piece of cotton fabric is attached to the finger of the crockmeter and a fixed load pushes it onto the surface of the material to be tested. The cotton is then dragged backwards and forwards ten times over a set distance, and the level of staining of the cotton fabric surface is evaluated. The test is often repeated with a wet cotton fabric. Rating is conducted on the cotton swab using the degree-of-staining grey scale (Figure 7.1a). Shade change of the material being measured can also be evaluated with the shade change grey scale (Figure 7.1b) but this is normally not a problem with motorcycle garments.

7.1.2 Wash fastness

Wash fastness is conducted on textile materials that are designed to be laundered after use. Wash fastness evaluates the colour change of a product during laundering, along with its propensity to stain and damage other garments washed with it. The method of wash fastness testing is dictated by the type of garment, washing instructions and fibre type. There are two main types of washing: domestic laundering and industrial laundering. Most garments for motorcycle use will be washed domestically, whereas clothing for use by professional riders (such as police uniforms) are more likely to receive industrial laundering.

Wash fastness is heavily influenced by the depth of shade. Deeper colours are more likely to have poorer wash fastness than lighter shades, as there is more dye present to wash off. Fibre type also has a substantial influence on wash fastness. High wash-fastness dyes and dyeing processes are available for nylon and polyester fabrics. Cotton and other cellulose fibres can also have high wash fastness; however, lower-price fabrics are more likely to be coloured with dyes with a lower wash fastness The fastness of products from new suppliers should be closely monitored.

Wash-fastness testing is conducted in a small container rotated at a constant temperature for a set period of time, to simulate agitation during laundering. The rectangular sample of fabric to be tested is first placed next to one or more fabric samples; then the samples are sewn together at the top and the bottom, to hold them adjacent to each other. The fabric wash sample is then placed into the container along with a wash solution, which is usually water and a detergent but may contain other chemicals (e.g. an acid or alkali, a bleach, a sequestrant and/or an optical brightening agent). The container may also have items such as stainless-steel balls added to provide increased agitation and abrasion during the wash process.

At the end of the washing cycle, the samples are taken out and rinsed, and the excess water is squeezed from them. The sewing at one of the ends is cut and the sample opened like the letter T to dry without the adjacent fabrics in contact with the sample fabric. After drying, the colour change in the sample fabric and the level of staining in the adjacent fabrics are evaluated using the appropriate grey scales.

Domestic laundering

The temperatures for domestic laundering and level of agitation during washing are generally lower than in industrial cleaning. This results in less dye migration, staining and colour fading.

Lower wash-fastness testing temperatures are used to simulate domestic laundering. Hand-washing testing is evaluated at lower temperatures and lower washing times.

Industrial laundering

The higher temperatures and increased agitation of industrial laundering can result in increased dye migration, staining and colour fading. Wash-fastness tests to simulate industrial laundering employ higher temperatures and may employ longer wash times, with the use of metal balls and disc abradants to increase agitation levels.

7.1.3 Waster fastness

Fastness to water tests are used to assess the level of staining that will occur to adjacent fabrics or skin when in contact with a wet fabric over an extended period, such as when clothing is left wet in a washing machine or basket for an extended period. For motorcycle clothing, fastness to water is a good way to simulate staining of the riders' undergarments and skin when riding for extended periods of time in the rain. Testing is particularly important for leather products with a deep shade, as they tend to have low fastness to water.

Water-fastness samples are prepared in the same way as wash-fastness samples, using one or more adjacent fabrics. The samples are first soaked in water for a set period before being squeezed between pad rollers to a controlled water content. Next, the samples are placed between two Perspex spacers and a constant pressure is applied (Figure 7.2). Finally, the samples are incubated at a fixed temperature for up to 24 hours before being rinsed, dried and evaluated in the same way as for wash-fastness testing.

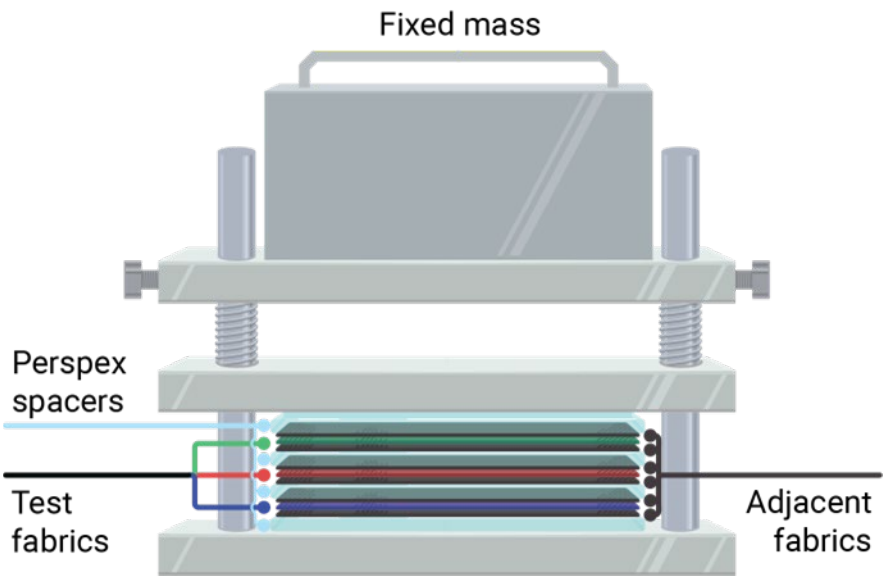


Figure 7.2: Water-fastness and perspiration-fastness test apparatus set up to apply constant pressure on the test samples.

7.1.4 Perspiration fastness

The thicker nature of protective clothing, combined with warm and humid summer riding conditions, increases the possibility of perspiration being absorbed into motorcycle clothing.

Perspiration is a complex solution that varies according to the wearer's metabolism. Perspiration can be either acidic or alkaline and contains large quantities of salts. The testing of perspiration fastness follows the same methods as water-fastness tests, with the chemical histidine used to simulate perspiration in the laboratory.

The international standard ISO 105-E04:2013 is the same as the Australian Standard AS 2001.4.E04-2005 Rec:2016, and both are appropriate for measuring perspiration fastness.

7.1.5 Light fastness

Colour fading is caused by light breaking down the individual dye molecules within the material, either changing their colour or rendering them colourless. Some dyes are more likely to break down than others, so dyers can tailor light-fastness resistance by selecting the right dyes during colouration. If you have a high requirement for light fastness, it is best to clearly specify this in fabric and garment orders, to ensure that appropriate dyes are selected during colouration. Some colours may not be available with very high light fastness. High-visibility colours and bleach whites typically have poor light fastness.

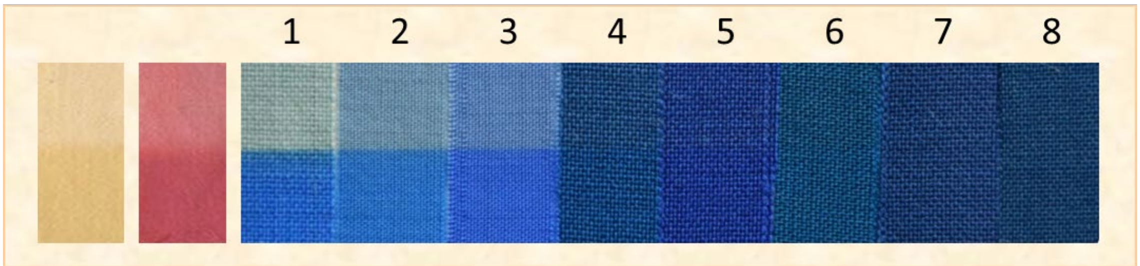
The depth of shade of a coloured material will have a strong influence on its light fastness. Lighter shades are more prone to colour change due to light exposure than are deeper shades.

Light fastness has a rating of 1–8, with 1 being poor light fastness and 8 being excellent. A series of blue wool fabrics, designed to fade at a controlled rate, are used to determine each of the ratings. Each number rating represents a fabric that takes twice as long to fade to a change-of-shade grey scale of 4 as the previous number rating; for example, a fabric with a light fastness rating of 2 takes twice as long to fade as a fabric with a rating of 1.

In light-fastness testing, samples are exposed to light for a fixed period. The samples to be tested are 50% covered with a light-impervious material. A set of blue wool fabrics are placed in the same manner under the same impervious material. Figure 7.3a shows the red and yellow samples partially covered by the light-impervious card and placed next to the blue wool fabrics. The test samples and blue fabrics are then exposed to the light source. When the fabric being assessed has a colour change of 4 on the grey scale, it is given the rating of the blue chip with the same level of fading.

Figure 7.3b shows the test samples after testing. The number 5 blue wool sample has a 4/5 colour change and the number 4 sample has a colour change of 4. The two samples measured would have had a rating of 3 as they are similar in colour change to the number 3 blue chip.

a



b

Figure 7.3: Light fastness test samples (a) prepared for testing with half the sample covered, and (b) after testing.

Light fastness can be conducted with a range of test equipment. The simplest method is to lay the samples flat in a space where they have direct sunlight exposure. Testing equipment is often employed to provide the light source, with one of the more commonly used being a xenon arc lamp. When testing, the amount of moisture in the samples and the temperatures that they reach during exposure will influence the level of fading. Some tests will incorporate weathering that includes water and salt sprays, along with light and dark periods.

The Australian Standard for light-fastness testing is AS2001.4.21, and it is recommended that a score of above 5 is achieved. ISO 105-B02:2013 is an alternative to the Australian Standard if manufacturing product for export to Europe.

7.2 Innocuousness

Consumers are becoming more aware of the presence of residual chemicals within garments that may release toxic, carcinogenic, mutagenic, allergenic, teratogenic and/or corrosive substances. Innocuousness tests can be used to determine if any of these substances are present. Using manufacturers of motorcycle-garment materials who are certified to deliver products to OEKO-TEX® Standard 100 or the bluesign® sustainability standard is another way of ensuring these chemicals will not be present in production.

The European motorcycle clothing standard EN 17092 utilises the requirements for innocuousness detailed in ISO 13688:2013 part 4.2.

Leather is tested additionally for pH to ensure that the tanning and dyeing processes have been neutralised appropriately. Measured pH should be above 3.5 and below 9.5 when tested according to ISO 4045.

The dark colours used in motorcycle clothing are often achieved using dyes mordanted with potassium dichromate. At the end of a dyeing cycle. there is the potential for residual hexavalent chromium (CrVI) to be present. This is a known carcinogen and should be avoided in clothing. Levels of CrVI are assessed according to ISO 17075, with a requirement of less than 3mg/kg.

Polychlorinated compounds can be used as fungicides and bactericides in the tanning of leather. Pentachlorophenol (PCP) was once commonly used and is sometimes found in imported leathers, but has now been mostly phased out due to its toxic nature. In some cases, it is substituted by tetrachlorophenol (TeCP), which is also toxic. The presence of PCP and TeCP should be no more than 0.5mg/kg.

7.3 Dimensional stability and laundering

The process of washing clothing exposes it to water and detergents, combined with agitation and heat (see also Section 7.1.2). This can cause a relaxation of fabrics, as it allows swelling and contraction of the structures, as well as movement of fibres and yarns. During textile and garment manufacture, residual strain can be placed into fabric. During the laundering process, these strains can be released, resulting in a change in dimensions and shape of the fabric. The most common effects are fabric-relaxation shrinkage and, in some cases, spirality (see Section 7.3.2, below).

European Standard EN 17092 utilises ISO 5077:2008 for the determination of dimensional change in washing and drying. Washing is normally conducted using ISO 13688:2013 part 5.2.

7.3.1 Fabric shrinkage

Fabric shrinkage is important in garment manufacture as it can influence garment sizes. Relaxation shrinkage occurs during the first one or more wash cycles of a new garment. The fabric shrinks in either the warp or the weft, or in both directions. As most garments are tried on for the first time before relaxation shrinkage has occurred, the laundering process can result in the change of the size of the garment. If size change is excessive, it will be noticed by the purchaser and result in complaints or returns.

For example, consider a pair of size 14 ladies' pants with an 86cm waist. If there is a 10% weft relaxation shrinkage in the fabric, then this would result in an 8.6cm reduction in waist to 77.4cm, which reduces the garment to a size 10. This level of shrinkage would result in buyer dissatisfaction and the product would likely be returned.

Fabric specifications should require relaxation shrinkage to be less than 5% in both the warp and weft directions of all fabrics used in manufacture. Most companies undertaking dyeing and finishing of fabrics have the capability to measure fabric-relaxation shrinkage, so it should be easy to have this result supplied with all fabrics.

The relaxation test can be conducted on garments after delivery and it is recommended that this is done with each new delivery, to ensure the product is within specification. Fabric-relaxation shrinkage is measured by a series of wash and dry cycles. Three to five cycles are normally conducted, to ensure relaxation is complete. Washing is done with a top-loading or front-loading washing machine, using a similar cycle and detergent to that specified on the garment care tag. The fabric is then dried flat, on a line or in a tumble dryer, with tumble drying having the largest effect on fabric dimensions. Drying between washes is important as it allows swollen fibres and yarns to return to their natural size and enables movement of the fabric during drying contractions.

Before washing for the first time the fabric should be conditioned at a constant temperature and humidity for at least 24 hours before it is marked up. A square of known dimensions is marked onto the conditioned fabric surface using an indelible pen or a needle and thread (Figure 7.4). After the final drying cycle, the fabric is again conditioned for 24 hours and the dimensions of the square remeasured. Dimensional changes in the length of the warp and weft sides of the square are calculated and converted into a percentage change. Conditioning before and after testing is important as atmospheric conditions may also alter the dimensions of a fabric.

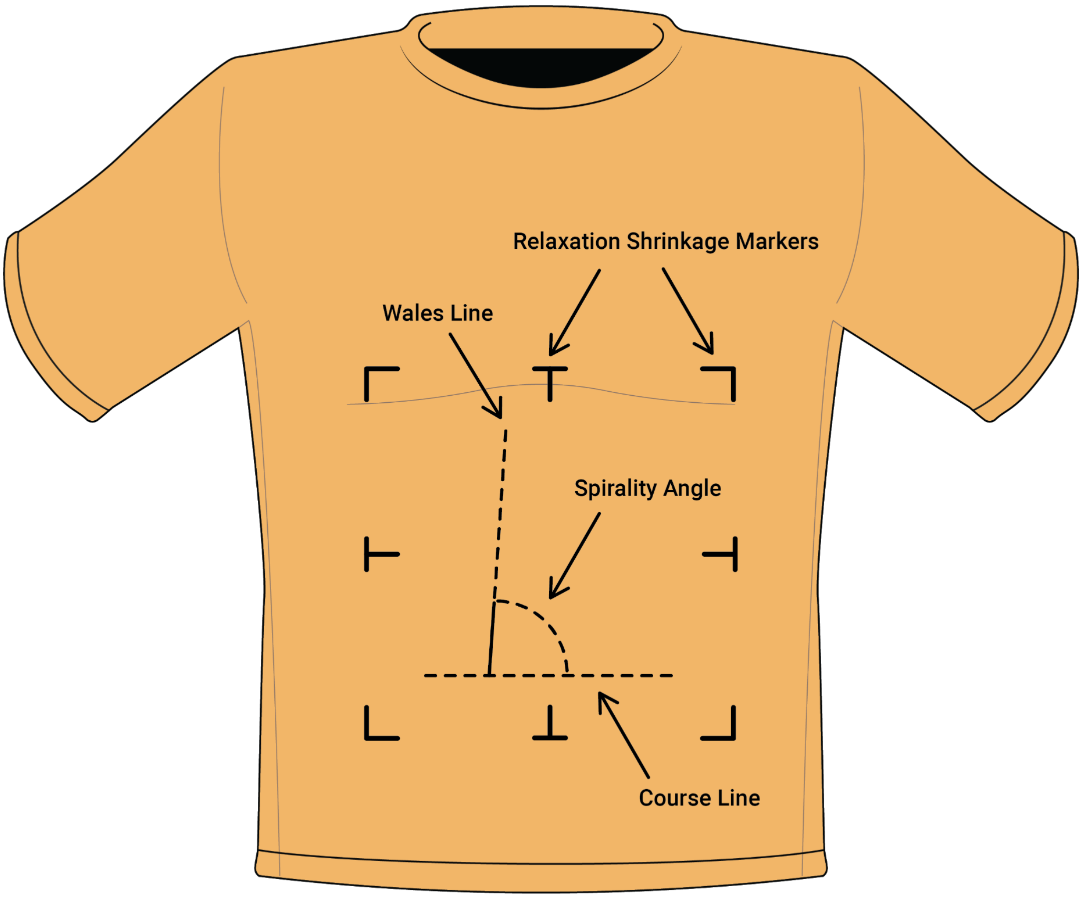


Figure 7.4: A T-shirt with markers for measuring relaxation shrinkage (solid lines) and spirality (dashed lines).

7.3.2 Spirality

Spirality is the change in dimensional stability of a knitted garment, resulting in a skewing of the angle the wale makes with the courses in a knitted fabric. When a singles yarn has a high twist it will distort the loop in one direction in a single jersey fabric. The higher the twist levels in the yarn, the higher the angle of spirality.

Spirality causes rotation of seams and can result in aesthetic issues for the garment. It may also cause the wearer discomfort if garment twisting results in shape change. Spirality normally comes from spinners increasing yarn twist due to using shorter-length (lower-cost) cotton fibres. Spirality can be avoided by using plied yarns in plain knit fabrics or ensuring that the mill is using cotton with a longer fibre length in yarn production. The maximum spirality usually allowed within a knitted fabric before its aesthetic appearance is affected is 4–6º.

Spirality should be measured at the same time as relaxation shrinkage using the same process. An additional two lines are added to the garment, using indelible pen or thread, before the first laundering cycle: the first is parallel with the wales in the knitted fabric, and the second is parallel with the courses (see Figure 7.4). The angle between the two lines is then measured and recorded. The fabric/garment is then washed using the same process as for relaxation shrinkage. After the final drying cycle and conditioning, the angle between the two lines is again measured. The degree of spirality is the difference between the two angles.

8 International manufacture

A large proportion of motorcycle protective clothing is commissioned by a clothing company but manufactured elsewhere. At one end of the scale, garments are fully designed by the commissioning company and made to exact specifications. At the other end, an international manufacturer will supply samples for the commissioning company to select from. No matter where the garments are manufactured, the process requires careful specification and monitoring to ensure that garments remain consistent over time.

Dealing with international manufacture can be difficult, and contracts should include clear and precise directions to reduce communication issues. One of the best ways to achieve this is through an extensive set of specifications.

This chapter has been developed to improve the experience of international manufacture, and it contains the following sections:

8.1 Specifications advised for yarn, fabric and garment manufacture.

8.2 The sampling that should be conducted to ensure garments remain within tolerances.

8.3 The non-destructive and destructive testing that should be considered to assess compliance.

8.1 Garment and materials specifications

Including detailed garment and material specifications in your contracts with manufacturers will help to ensure that your products comply with your requirements in their first delivery and in subsequent orders. Written, agreed specifications help prevent faulty or out-of-specification products being delivered. These specifications, as well as clear procedures for dealing with any failings and costs involved, are particularly important if you need to make a claim.

The following elements should be included in the specifications to manufacturers.

8.1.1 Materials

Materials usually refers to all of the elements from which a garment is constructed. Materials should be specified by a commissioning company to the contracting manufacturer of their product. Some companies may have developed their own fabrics; in this case, they will also need to specify the yarns that are used in the fabrics and fabric construction. Where a company is purchasing an off-the-shelf option from a contract manufacturer, then reverse engineering of the demonstrator garment can be done to collect each of the items required for the specification of production garments.

Yarns

Yarns come in a range of different specifications. Spun and continuous-filament yarns are the two main types. There are many different count systems for specifying the mass per unit length, including denier, tex, decitex, English cotton count, metric count and worsted count. Different yarn providers will use different count systems depending on their background. It is recommended that the yarn count is specified in a count familiar with the manufacturer, such as the English cotton count, and is backed up by the tex count as this helps to avoid confusion. The key specifications for yarns are given in Table 8.1.

Table 8.1: Yarn specifications.

Dimension	Variable
Yarn type	Continuous Spun
Count	Manufacturer-preferred count and tex (g/1,000m)
Breaking strength	Force to break (N)
Stretch	Percentage stretch (%) Method of stretch
Continuous-filament yarns	Number of filaments Texturising method Twist (turns per metre)
Spun yarns	Spinning method (ring, open-end, vortex, core spun, etc.) Twist (turns per metre) Twist direction (S or Z) Twist factor Evenness (thick, thin, neps) Fibre composition (%) Number of plies Ply twist (turns per metre) Ply twist direction (S or Z)

Fabrics

Fabrics and leathers can come in a range of specifications. One of the most important measures is the fabric weight. This governs many of the protective properties of the fabric. Some factors, such as tear resistance and weight per unit area, are easy for a contracting manufacturer to measure and they often have this capacity in-house. Specialty measurements, such as abrasion resistance, should only be specified if there is an ability for the fabric provider or contract manufacturer to measure these properties, or to commission a local test laboratory that operates the same apparatus. Some tests are not appropriate for some fabrics. For example, a tensile test is appropriate for woven fabrics but inappropriate for knitted fabrics.

Table 8.2 provides the key elements that should be specified for fabrics.

Table 8.2: Material specifications.

Dimension	Variable	Advised specification
Material structure	Weave pattern and density Knit pattern and cover factor Leather type and thickness (mm)	Threads per 10cm in warp and weft Loops in courses and wales Full grain, top grain and suede
Fibre type	Pure or blend	% of each fibre type
Fabric weight	Mass per unit area (g/m^2)	±5% tolerance

Dimension	Variable	Advised specification
Dimensional stability	Shrinkage Spirality	≤3% length and width ≤5°
Tensile strength	Force to break 20mm-wide strip (N)	Shell materials ≥1,400N
Tear strength	Force to tear (N)	Shell materials ≥50 N Lining materials ≥30 N
Burst strength	Pressure to burst (kPa)	Shell materials ≥1,000 kPa Lining materials ≥600 kPa
Abrasion resistance	Cambridge impact abrasion Darmstadt Impact abrasion	As per zone requirements As per zone requirements
Cut resistance	Falling blade	As required by zone
Colour	Shade difference from control	≤0.8 ΔE
Colour fastness	Light Rub/crocking Water Wash Perspiration	≥5 ≥4/5 ≥4/5 ≥4/5 ≥4/5
Water resistant barrier	Type Water resistance	Laminated to shell fabric 10,000mmH_2O

Fastenings

The type and force of closure of fasteners – zips, buttons, clips, hooks, press studs, and hook-and-loop fasteners – can be measured. The force to open the closure in newtons (N) should be specified.

8.1.2 Garments

Garment specifications should detail the requirements to make the garment. They include the size; types of seams; types of impact protectors; embellishments; printing; and the placement of fasteners, protective liners, comfort liners and shell material. The critical construction elements are discussed below.

Garment size

Dimensions for each garment size in a product range should be specified. A tolerance above and below the allowable size is required to allow for variation in manufacture. The tolerance will vary from garment to garment but should be low enough that variation does not allow a garment to change size if at the minimum or maximum range of the tolerance. The easiest method to enable evaluation of garment size is to create a garment size template and dimensions table (Figure 8.1), with critical measurements listed for quick reference.

It is important to monitor garment sizes of supplied products, especially if buying on a cost-per-item basis, as contracted manufacturers may produce garments to the minimum size tolerance to reduce their input material costs. Some unscrupulous operators may reduce sizing further in reorders if they feel that the client is not monitoring their sizes.

Pants size	Dimension (cm)					
	Waist	Inseam	Hip	Rise	Thigh	Cuff
44	112	81	130	41	79	48
46	117	81	137	41	81	48
48	122	81	142	41	84	48
50	127	81	145	41	86	48
52	132	81	147	41	89	51
54	137	81	150	43	91	51

Figure 8.1: Garment dimensions template and table for example only.

Seams

Seams are a critical component in the protection level of a garment. Further information on seam construction is given in Chapter 5. Different areas of a garment will have different requirements depending on the materials being joined and the impact risk zone. Table 8.3 details the key elements of a seam that need to be specified.

Table 8.3: Seam specifications.

Dimension	Variable
Seam location	Placement of the seam according to the impact risk zones
Sewing thread specifications	Material composition Count (tex) Tensile strength (N)
Number of external seams	Seams through the external shell material
Number of hidden seams	Seams covered by the shell materials
Stitch type	Includes plain and overlocked
Stitch length	Stiches per 10cm

Impact protectors

Impact protectors are placed in areas of a garment according to defined levels of impact risk. Further information on impact protectors is given in Sections 2.9 and 5.5. The type and fixation of these impact protectors requires specification. This should include the EN 1621-1:2012 specifications of limb type, size and protection level. It may also include different size protectors for different size garments. An example of this would be a Type A impact protector in small and medium garments and a Type B impact protector for garments that are size large or larger.

Labelling

Labelling is an important component within a protective garment. Further information is given on labelling in Section 6.1. The position, size and type of labels should be specified to ensure that point-of-sale regulatory obligations are met. The key labelling required in all garments includes material composition, country of manufacture, sizing and care instructions. Additionally, size of wearer and CE certification may be required for some locations. It is important to specify the size and type of label to be attached, as an undersized label may not meet the regulatory obligations.

8.2 Sampling

Garments received from a contract manufacturer must be tested to confirm that they remain within specification. Sampling should be undertaken when each new production run is received from a contract manufacturer. There are detailed sampling plans available from many online sources; however, as a minimum it is recommended that at least three garments are randomly sampled from each production run. These should not all come from the one box.

If visiting a contract manufacturer, it is highly advisable to do sampling from the production-line completed garments in front of the representative of the company. This will establish with them that you have a quality control system in place and that there could be repercussions for product that is out of specification. It will often increase the care that goes into manufacturing your products.

8.3 Testing

Testing of completed garments is important to ensure that they meet the design specifications. Testing can be conducted using both destructive and non-destructive methods. Test results should be recorded and referred to with each subsequent batch to see if there is subtle variation occurring. It is recommended to keep one "as supplied" garment from each batch to refer to, for products where repeated production runs will occur over several years.

8.3.1 Visual assessment

The simplest form of quality-control testing is through visual assessment, which can be rapidly done with limited resources. The simplest form is by comparing one garment with another. Visual assessment should be conducted on all elements within the garment, including materials, colour, fasteners, impact protectors and seams. Visual assessment of the garment sizing can be completed using a ruler to assess the garment size, ensuring it is within specified tolerances.

Photography can be used to obtain magnified comparisons of detailed elements within a garment. Placing a metal ruler over the element then photographing it enables fabric and seam construction to be quantifiably assessed. The images can be stored for future reference with subsequent production runs.

The assessment used for seams is an example of how visual assessments are conducted. Magnified photographs of a stitch run can be used to count stitch frequency and the number of stitch runs, and assess the position of stitches within the seam. The inside of seams can be assessed, counting the number of hidden stitch runs, and identifying the presence of gluing and seam sealing where appropriate. Damage from needle cutting can be observed with a magnifying glass or magnified photographic image.

8.3.2 Destructive testing

Destructive testing is often required to measure important components within a constructed garment. Simple destructive testing can often be carried out in-house to enable quantification without having to resort to external certified testing. Some destructive testing, such as seam strength and abrasion resistance, may need to be conducted by a third party as it requires specialised equipment.

Until a relationship is established with a contract manufacturer, it is recommended that external quantified testing is sought. Tests that should be considered as a minimum requirement are given in Table 8.4, along with a simple method to achieve them. If the result of a simple test is of concern and a claim against the contract manufacturer is required, it is recommended that certified external testing is done to provide evidence.

Table 8.4: Destructive testing that can be carried out in-house with simple test equipment.

Measured dimension	Simple test method
Fabric mass	1. Cut at least four square 100 × 100mm samples of a fabric type from the garment. 2. Weigh them together on an accurate balance. 3. Divide the total mass by 4, then multiply by 100 to give the fabric mass in g/m^2.
Dimensional stability	1. Mark up the garment as shown in Figure 7.4. 2. Domestically launder the garment and dry the desired number of times. 3. Measure the amount of shrinkage and spirality.
Leather thickness	1. Cut a cross-section through the leather. 2. Use a vernier calliper to measure the leather thickness in millimetres. Be careful not to apply too much clamping force as this will squash the leather, giving a false reading. 3. Take at least ten measurements over the garment and average the result.
Colour fastness to washing	1. Cut 100 × 20mm samples of each of the coloured fabrics and sew each one next to a white nylon and a white cotton fabric. 2. Place each fabric into a small glass jar with 100ml of 60°C water with a strong domestic laundry detergent. 3. Agitate the jar regularly over a 30-minute period before removing the sample and drying. 4. Visually observe the staining of the nylon and cotton, and the colour change of the fabric sample.
Colour fastness to rubbing	1. Attach a small sample of white cotton fabric over the end of a flat rod and hold in place with an elastic band. 2. Holding the cotton-covered rod end flat on the coloured fabric to be measured, draw it backwards and forwards ten times over a 100mm distance while applying a constant pressure. 3. Repeat with a wet piece of cotton on the end of the rod. 4. Visually assess colour staining on the cotton fabric.

Appendix A: Abrasion test results

Table A.1 shows the impact abrasion test results for a range of materials, measured using EN13595-2:2002. These are the approximate abrasion times that may be expected by each material combination. It is recommended that the abrasion times for the final material combination of your designs should be confirmed by testing. A number of these shell materials and material combinations are also represented in the tensile, burst, thermal and air permeability test results given in the following appendices. Note that '× 2' refers to two layers of shell fabric.

Table A.1: Impact abrasion-resistance test results in seconds (s) for different shell materials by themselves, with a comfort mesh liner (CML), and with a para-aramid double jersey layer and comfort mesh liner (p-A + CML).

Layer details →	Shell fabric		Shell + CML		Shell + p-A + CML	
Abrasion resistance (s) → ↓ Shell details	Mean	SD	Mean	SD	Mean	SD
500D nylon	0.32	0.063	0.5	0.055	2.65	0.168
500D nylon × 2	0.81	0.125	0.97	0.163	5.29	0.680
600D polyester	0.17	0.028	0.38	0.038	2.89	0.265
600D polyester × 2	0.65	0.145	0.93	0.297	6.20	1.362
1680D nylon	0.58	0.156	1.04	0.137	4.4	0.268
1680D nylon × 2	2.62	0.419	3.94	0.765	11.7	2.534
500D mesh fabric	0.31	0.012	0.34	0.028	2.49	0.134
500D mesh fabric × 2	0.90	0.078	1.18	0.111	5.97	1.346
Fleecy	0.14	0.044	0.15	0.026	1.12	0.3
Denim	0.52	0.054	0.78	0.113	3.25	0.238
Chino	0.12	0.037	0.16	0.026	1.45	0.211
Full grain leather (2.4mm)	7.57	0.997	10.53	1.672	15.21	2.895
Perforated full grain leather (1.65mm)	5.25	1.414	6.06	0.747	11.41	0.698

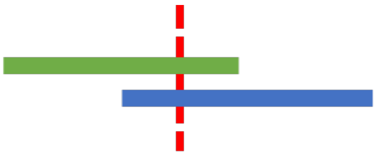
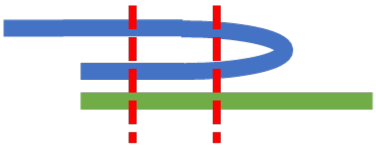
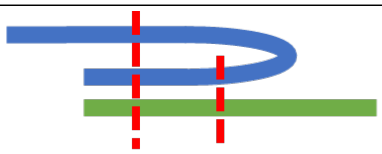
Appendix B: Burst and tensile test results

Seam strength may be tested by either hydraulic burst or tensile testing. The type of fabric, the type of seam and the geometry of the seam in the fabric all affect the performance of a seam.

Table B.1 details the different symbols used to describe the seams that have been tested. Tables B.2 and B.3 list the burst and tensile performance of common motorcycle clothing materials, including leather, nylon woven, nylon mesh and protective denim fabrics.

A third fabric layer has been added to some of the textile test samples. The third layer added to the nylon and mesh fabrics was an additional layer of the primary fabric, whereas for protective denim samples, it was a layer of 350g/m^2 para-aramid double jersey knitted fabric. For the protective denim fabric samples in Table B.1, the blue and green lines each represent a layer of denim fabric, while the grey line represents the para-aramid double jersey fabric.

Table B.1: Legend of seam descriptive symbols.

Legend	Description
	Three fabric layers
	Overlocking
	Single layer of stitching
	Two layers of stitching through all layers
	Two layers of stitching with the left through all layers and the right hidden to the outside layer

Leather and perforated leather

Table B.2 provides the seam strength results for five different seam types in a normal and a perforated leather. The leather seams tested were for single layers of leather material joined in different configurations. Seams with the greatest strength were those in which the first line of stitching was concealed and protected by the leather being folded over and then restitched; these seams are suitable for use in motorcycle clothing shells, particularly in the high-impact risk zones. Seam LS5 is more suited for use in low injury-risk areas only.

Table B.2: Tensile strength and burst strength test results of leather samples with different seam methods.

Sample details → **Test method →** **↓ Seam method and number**	**Full grain leather (2.4mm)** Tensile strength (N/mm) **Burst strength (kPa)**	**Perforated full grain leather (1.65mm)** Tensile strength (N/mm) **Burst strength (kPa)**
LS1 	14.8 **1889**	12.8 **827**
LS2 	16.1 **870**	11.8 **962**
LS3 	18.7 **1160**	17.0 **900**
LS4 	16.9 **1254**	13.2 **1103**
LS5 	14.8 **733**	10.2 **789**

Woven textiles

The best performing seams in woven fabrics involved two or more lines of stitching. A single line of stitching combined with an overlocked edge did not produce seams as secure as those with the equivalent two lines of stitching. Seam slippage and fabric strength had an influence on seam strength. This is displayed in Table B.3 by the difference in results between the 500D and 1680D woven nylon fabrics with the same seam – the 500D repeatedly performed poorly. Adding a sewn patch (represented by the grey line) over the top of critical seams improved the seam performance for all patch-covered seam types (TS9 to TS14).

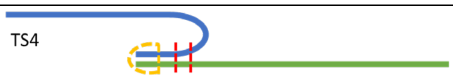
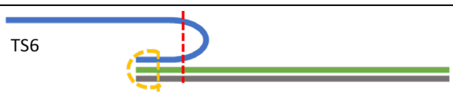
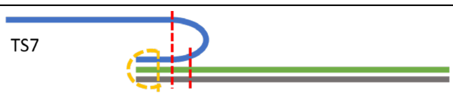
Mesh textiles

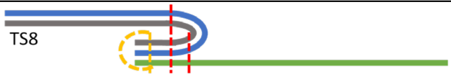
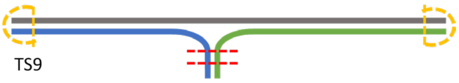
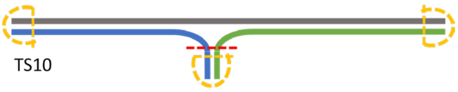
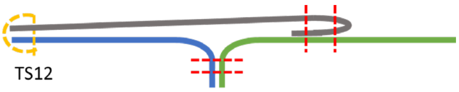
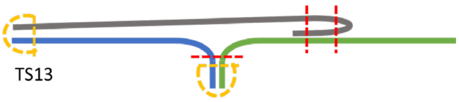
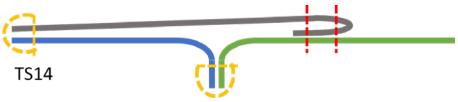
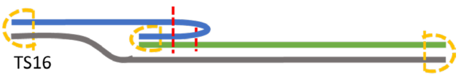
Seams in mesh fabrics do not perform as well as the equivalent seams in a woven fabric. This is due to the strength of the fabric and the limited material in the seam where stitching occurs. Two or more lines of stitching are required to achieve structurally secure seams. Adding a sewn patch over the top of critical seams had the same benefits in improving the seam performance in mesh fabric as in woven fabrics.

Protective denim

The lower fabric strength of denim, combined with the potential for slippage of yarns in the edge of the fabric, resulted in lower seam strengths for protective denim when compared with protective textiles. Improving the tensile strength and thread retention within the denim would improve the strength of seams in protective denim garments. Two lines of stitching should be considered the minimum in protective denim garments to achieve structurally sound seams.

Table B.3: Tensile strength and burst strength test results of textile samples with different seam methods.

Sample details →	**500D nylon**	**1680D nylon**	**500D mesh fabric**	**Protective denim fabric**
Test method → **↓ Seam method and number**	Tensile strength (N/mm) **Burst strength (kPa)**	Tensile strength (N/mm) **Burst strength (kPa)**	Tensile strength (N/mm) **Burst strength (kPa)**	Tensile strength (N/mm) **Burst strength (kPa)**
TS1 	16.4 **917**	14.4 **1246**	23.2 **1034**	17.5 **489**
TS2 	12.1 **851**	10.0 **936**	7.6 **428**	11.8 **365**
TS3 	16.4 **962**	13.4 **1209**	13.2 **710**	12.6 **851**
TS4 	8.2 **1315**	7.9 **1521**	9.7 **510**	8.8 **285**
TS5 	16.6 **900**	13.2 **1213**	23.1 **1094**	13.7 **907**
TS6 	11.3 **919**	14.2 **853**	8.1 **418**	11.8 **811**
TS7 	16.3 **1037**	16.3 **1380**	12.6 **672**	12.2 **852**

Sample details → **Test method →** **↓ Seam method and number**	**500D nylon** Tensile strength (N/mm) **Burst strength (kPa)**	**1680D nylon** Tensile strength (N/mm) **Burst strength (kPa)**	**500D mesh fabric** Tensile strength (N/mm) **Burst strength (kPa)**	**Protective denim fabric** Tensile strength (N/mm) **Burst strength (kPa)**
 TS8	16.3 1434	13.8 1585	11.7 1061	12.5 827
 TS9	31.6 1844	41.8 1344	28.5 1949	
 TS10	36.5 1867	29.6 1946	27.1 1897	
 TS11	29.5 1795	30.4 1942	32.0 1905	
 TS12	20.7 1394	18.6 1922	23.4 1706	
 TS13	22.4 1367	25.9 1941	22.6 1946	
 TS14	21.4 1321	19.0 1447	25.2 1610	
 TS15				16.0 981
 TS16				14.2 981

Appendix C: Thermal and air permeability test results

Thermal comfort (I_{MT}) can be measured as the thermal resistance of a fabric combined with its moisture vapour permeability. Garments with high air permeability typically have reasonable moisture vapour permeability and resultant thermal comfort. Examples of fabrics with good results for thermal comfort are the mesh and denim fabric combinations. The air permeability results show that this is due to airflow through the material structure.

The perforated leather also allowed for airflow through its structure but did not perform as well as the denim and mesh fabrics for breathability. The 500D and 1680D woven nylon fabrics performed poorly as the tight weave structure and moisture-resistant membrane restrict moisture vapour transmission.

Table C.1 provides performance values for different materials and material combinations for thermal resistance, moisture vapour permeability, I_{MT} and air permeability. CML refers to a comfort mesh liner, DJK is a double jersey knit fabric and TK is a terry knit fabric.

Table C.1: Thermal and air permeability test results.

Test method	Thermal resistance	Moisture vapour permeability	I_{MT}	Air permeability
Sample name	**degC.m²/W**	**Pa.m²/W**	**No unit**	**cm³/cm²/s**
Full grain leather (2.4mm)	0.1113	48.12	0.1388	0.051
Full grain leather + CML	0.1182	49.34	0.1437	0.047
Perforated full grain leather (1.65mm)	0.0957	33.19	0.1729	49.46
Perforated full grain leather + CML	0.1180	33.37	0.2122	39.26
Thin full grain leather (1.70mm)	0.1081	58.49	0.1109	0.020
Thin full grain leather + CML	0.1208	59.43	0.1220	0.018
500D mesh fabric	0.0908	10.16	0.5361	393.0
500D mesh fabric + CML	0.0975	11.43	0.5116	225.6
500D mesh fabric × 2	0.1114	14.71	0.4542	277.6
500D mesh fabric × 2 + CML	0.1178	16.36	0.4320	182.4
500D nylon	0.0918	145.16	0.0379	0.041
500D nylon + CML	0.0988	142.73	0.0415	0.036

Test method	Thermal resistance	Moisture vapour permeability	I_{MT}	Air permeability
Sample name	**degC.m²/W**	**Pa.m²/W**	**No unit**	**cm³/cm²/s**
500D nylon + membrane + CML	0.1203	132.51	0.0545	0.036
500D nylon × 2	0.1087	137.81	0.0473	0.045
500D nylon × 2 +CML	0.1179	212.79	0.0332	0.041
1680D nylon	0.0915	198.61	0.0276	0.123
1680D nylon + CML	0.1035	194.06	0.0320	0.117
1680D nylon + membrane + CML	0.1277	205.26	0.0373	0.111
Denim	0.102	12.17	0.5018	3.41
Denim + CML	0.111	13.74	0.4828	3.63
Denim + para-aramid DJK + CML	0.125	19.23	0.3884	3.66
Denim + para-aramid TK + CML	0.166	20.70	0.4803	3.60

Reference materials

Publications

ACEM, 2004. *Maids in-depth investigation of accidents involving powered two wheelers: Final report 1.2*. Association of European Motorcycle Manufacturers (ACEM), Brussels.

Albanese, B., Gibson, T., Whyte, T., Meredith, L., Savino, G., De Rome, L., Baldock, M., Fitzharris, M., Brown, J., 2017. Energy attenuation performance of impact protection worn by motorcyclists in real world crashes. *Traffic Injury Prevention* 18, S116–S121.

Albanese, B., Meredith, L., Whyte, T., Gibson, T.J., de Rome, L., Fitzharris, M., Baldock, M., Brown, J., 2015. *Protective clothing and impact protection for motorcyclists.* Paper presented at 12th Australasian Injury Prevention and Safety Promotion Conference, Sydney.

Allen, T., Newstead, S., Lenné, M.G., Mcclure, R., Hillard, P., Symmons, M., Day, L., 2017. Contributing factors to motorcycle injury crashes in Victoria, Australia. *Transportation Research Part F: Traffic Psychology and Behaviour* 45, 157–168.

Błazejczyk, K., Jendritzky, G., Bröde, P., Fiala, D., Havenith, G., Epstein, Y., Psikuta, A., Kampmann, B., 2013. An introduction to the Universal Thermal Climate Index (UTCI). *Geographia Polonica* 86 (1), 5–10.

Brown, J., Fitzharris, M., Baldock, M., Albanese, B., Meredith, L., Whyte, T., Oomens, M., 2015. *Motorcycle in-depth crash study*. Austroads Research Report AP-R489-15, Sydney.

Caldwell, J.N., Engelen, L., van der Henst, C., Patterson, M.J., Taylor, N.A.S., 2011. The interaction of body armor, low-intensity exercise, and hot-humid conditions on physiological strain and cognitive function. *Military Medicine* 176 (5), 488–493.

Cavallo, V., Pinto, M., 2012. Are car daytime running lights detrimental to motorcycle conspicuity? *Accident Analysis & Prevention* 49, 78–85.

Cole, B.L., Hughes, P.K., 1984. A field trial of attention and search conspicuity. *Human Factors* 26 (3), 299–313.

Dai, X.-Q., Havenith, G., 2016. The interaction of clothing ventilation with dry and evaporative heat transfer of jackets: The effect of air and vapor permeability. *International Journal of Clothing Science and Technology* 28 (5), 570–581.

de Rome, L., 2019. Could wearing motorcycle protective clothing compromise rider safety in hot weather? *Accident Analysis & Prevention* 128, 240–247.

de Rome, L., Brandon, T., Hurren, C., 2021. *The crash study: An epidemiological approach to the analysis of motorcycle crashes in Tasmania, 2012–2016*. Deakin University, Geelong.

de Rome, L., Fitzharris, M., Baldock, M., Fernandes, R., Ma, A., Brown, J., 2016. The prevalence of crash risk factors in a population-based study of motorcycle riders. *Injury* 47 (9), 2025–2033.

de Rome, L., Gibson, T., Haworth, N., Ivers, R., Sakashita, C., Varnsverry, P., 2012. *Improving consumer information about motorcycle protective clothing products*. Report prepared for the Motor Accidents Authority of NSW (MAA). The George Institute for Global Health, Sydney.

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 & Prevention* 43 (6), 1893–1900.

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* 43, 2035–2045.

de Rome, L., Ivers, R., Haworth, N., Heritier, S., Du, W., Fitzharris, M., 2011. Novice riders and the predictors of riding without motorcycle protective clothing. *Accident Analysis & Prevention* 43 (3), 1095–1103.

de Rome, L., Meredith, L., Ivers, R., Brown, J., 2014. Validation of the principles of injury risk zones for motorcycle protective clothing. *Journal of Safety Research* 50, 83–87.

de Rome, L., Taylor, E.A., Croft, R.J., Brown, J., Fitzharris, M., Taylor, N.A.S., 2015. Thermal and cardiovascular strain imposed by motorcycle protective clothing under Australian summer conditions. *Ergonomics* 59 (4), 504–513.

de Rome, L., Taylor, N.A.S., Troynikov, O., Hurren, C., Fitzharris, M., Croft, R., Brown, J., 2015. *Motorcycle protective clothing: Physiological and perceptual barriers to their summer use.* Paper presented at ARSC 2015: Australasian Road Safety Conference, Gold Coast, Qld.

European Experimental Vehicles Committee (EEVC), 1993. *Report on motorcycle safety: Report of the Ad-hoc Group on Motorcycle Safety.* EEVC, Brussels.

Faerevik, H., Reinertsen, R.E., 2003. Effects of wearing aircrew protective clothing on physiological and cognitive responses under various ambient conditions. *Ergonomics* 46 (8), 780–799.

Gershon, P., Ben-Asher, N., Shinar, D., 2012. Attention and search conspicuity of motorcycles as a function of their visual context. *Accident Analysis & Prevention* 44 (1), 97–103.

Gershon, P., Shinar, D., 2015. Powered two-wheelers' conspicuity: The effects of visual context and awareness. In L. Rößger, M.G. Lenné, eds. *Increasing motorcycle conspicuity: Design and assessment of interventions to enhance rider safety.* CRC Press, London, pp. 183–210.

Haworth, N., Debnath, A.K., 2013. How similar are two-unit bicycle and motorcycle crashes? *Accident Analysis & Prevention* 58, 15–25.

Horswill, M.S., Helman, S., Ardiles, P., Wann, J.P., 2005. Motorcycle accident risk could be inflated by a time to arrival illusion. *Optometry and Vision Science* 82 (8), 740–746.

Houshyar, S., Padhye, R., Nayak, R., 2017. Effect of moisture-wicking materials on the physical and thermo-physiological comfort properties of firefighters' protective clothing. *Fibers and Polymers* 18 (2), 383–389.

King, M.J., Wood, J.M., Lacherez, P.F., Marszalek, R.P., 2012. Optimism about safety and group-serving interpretations of safety among pedestrians and cyclists in relation to road use in general and under low light conditions. *Accident Analysis & Prevention* 44 (1), 154–159.

Koch, H., Brendicke, R., 1998. Protective clothing: Wearing patterns, knowledge and attitudes of motorcyclists. In T. Rothengatter, R. De Bruin, eds. *Road user behaviour: Theory and research.* Van Gorcum & Company, Assen, Netherlands, pp. 225–231.

Langham, M.P., Moberly, N.J., 2003. *An evaluation of alternative police uniform designs for increased conspicuity in the road environment.* University of Sussex, Falmer, UK.

Mannering, F.L., Grodsky, L.L., 1995. Statistical analysis of motorcyclists' perceived accident risk. *Accident Analysis & Prevention* 27 (1), 21–31.

McLellan, T.M., Havenith, G., 2016. Protective clothing ensembles and physical employment standards. *Applied Physiology, Nutrition, and Metabolism/Physiologie appliquee, nutrition et metabolisme* 41 (6), S121–S130.

Meredith, L., Brown, J., Ivers, R., de Rome, L., 2013. Distribution and type of crash damage to motorcyclists' clothing: Validation of the zone approach in the European Standard for motorcycle protective clothing, EN-13595. *Traffic Injury Prevention* 15 (5), 501–507.

Meredith, L., Hurren, C., Clarke, E., Fitzharris, M., Baldock, M., de Rome, L., Olivier, J., 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, 1–7.

Moberly, N.J., Langham, M.P., 2002. Pedestrian conspicuity at night: Failure to observe a biological motion advantage in a high-clutter environment. *Applied Cognitive Psychology* 16 (4), 477–485.

Nazemetz, J.W., Bents, F.D., Perry, J.G., Thor, C., Mohamedshah, Y.M., 2019. *Motorcycle crash causation study: Final report.* US Department of Transportation, Federal Highway Administration, McLean, VA.

Otte, D., Middelhauve, V., 1987. Quantification of protective effects of special synthetic protectors in clothing for motorcyclists. In D. Cesari, A. Charpenne, eds. *Proceedings of 1987 International IRCOBI Conference on the Biomechanics of Impacts.* IRCOBI Secretariat, Bron, France, pp. 1–18.

Otte, D., Schroeder, G., Richter, M., 2002. Possibilities for load reductions using garment leg protectors for motorcyclists – a technical, medical and biomechanical approach. In *Proceedings of the 46th Annual Meeting of the Association for the Advancement of Automotive Medicine.* AAAM, Barrington, IL, pp. 367–385.

Pai, C.-W., 2011. Motorcycle right-of-way accidents – a literature review. *Accident Analysis & Prevention* 43 (3), 971–982.

Ranchet, M., Cavallo, V., Dang, N.T., Vienne, F., 2016. Improving motorcycle conspicuity through innovative headlight configurations. *Accident Analysis & Prevention* 94, 119–126.

Saleh, P., Golias, J., Yannis, G., et al., 2010. *Interaction between powered two-wheeler accidents and infrastructure; Powered two wheelers – safety measures: guidelines, recommendations and research priorities.* 2-BE-SAFE: 2-Wheeler Behaviour and Safety, Paris.

Udayraj, Talukdar, P., Das, A., Alagirusamy, R., 2016. Heat and mass transfer through thermal protective clothing – a review. *International Journal of Thermal Sciences* 106, 32–56.

Underwood, G., Humphrey, K., van Loon, E., 2011. Decisions about objects in real-world scenes are influenced by visual saliency before and during their inspection. *Vision Research* 51 (18), 2031–2038.

Wells, S., Mullin, B., Norton, R., Langley, J., Connor, J., Lay-Yee, R., Jackson, R., 2004. Motorcycle rider conspicuity and crash related injury: Case-control study. *British Medical Journal* 328 (7444), 857.

Wood, J.M., Tyrrell, R.A., Marszalek, R., Lacherez, P., Carberry, T., 2013. Bicyclists overestimate their own night-time conspicuity and underestimate the benefits of retroreflective markers on the moveable joints. *Accident Analysis & Prevention* 55, 48–53.

Woods, R.I., 1994. *The Cambridge Standard for motorcyclists' clothing – Part 1: Jackets, trousers, one-piece suits and two-piece suits intended to provide mechanical protection against some injuries on metalled road surfaces.* Cambridge University Technical Services Ltd, Cambridge, UK.

Woods, R.I., 1996a. Specification of motorcyclists' protective clothing designed to reduce road surface impact injuries. In J.S. Johnson, S.Z. Mansdorf, eds. *Performance of protective clothing: Fifth volume.* American Society for Testing and Materials, Philadelphia, pp. 3–22.

Woods, R.I., 1996b. 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*: Fifth volume.* American Society for Testing and Materials, Philadelphia, pp. 43–56.

Woods, R.I., 1999. *The Cambridge Standard for motorcyclists' clothing – Part 1: Jackets, trousers, one piece suits and two piece suits, designed to provide mechanical protection against some injuries. Issue 2.* Cambridge University, Cambridge, UK.

Wulf, G., Hancock, P., Rahimi, M., 1989. Motorcycle conspicuity: An evaluation and synthesis of influential factors. *Journal of Safety Research* 20, 153–176.

Zwolinska, M., 2013. Thermal subjective sensations of motorcyclists. *Accident Analysis & Prevention* 50, 1211–1220.

Standards

AS/NZS 1344-1997, Size coding scheme for women's clothing - Underwear, outerwear and foundation garments, Standards Australia

AS/NZS 1957, Textiles – Care labelling, Standards Australia

AS/NZS 2001.4, Textiles – Colourfastness tests, Standards Australia

AS/NZS 2332, Slide Fasteners, Standards Australia

AS/NZS 4501.2:2006, Occupational Protective Clothing General Requirements, Standards Australia

AS/NZS 4602.1:2011, High visibility safety garments – Part 1: Garments for high-risk applications, Standards Australia

EN 1621-1:2012, Motorcyclists' clothing protecting against mechanical impact – Motorcyclists' limb joint impact protectors, European Committee for Standardization

EN 1621-2:2014, Motorcyclists' clothing protecting against mechanical impact – Motorcyclists' back protectors, European Committee for Standardization

EN 1621-3:2018, Motorcyclists' clothing protecting against mechanical impact – Motorcyclists' chest protectors, European Committee for Standardization

EN 1621-4:2013, Motorcyclists' clothing protecting against mechanical impact – Motorcyclists' inflatable protectors, European Committee for Standardization

EN 13402 parts 1-3:2017, Size designation of clothes, European Committee for Standardization

EN 13594:2015, Protective gloves for motorcycle riders, European Committee for Standardization

EN 13595 parts 1-4:2002, Protective clothing for professional motorcycle riders – Jackets, trousers and one piece or divided suits, European Committee for Standardization

EN 17092 parts 1–6:2020, Protective clothing for motorcycle riders, European Committee for Standardization

EN 17353:2020, Protective clothing. Enhanced visibility equipment for medium risk situations. Test methods and requirements, European Committee for Standardization

ISO 105 – Textiles – Tests for colour fastness, International Organization for Standardization

ISO 3377-1:2011 – Leather – Physical and mechanical tests, International Organization for Standardization

ISO 3377-2:2016 – Leather – Physical and mechanical tests, International Organization for Standardization

ISO 4045:2018 – Leather – Chemical tests – Determination of pH and difference figure, International Organization for Standardization

ISO 4674-1:2016 – Rubber or plastics or coated fabrics – Determination of tear resistance – Part 1: Constant rate of tear methods, International Organization for Standardization

ISO 5077:2007 – Textiles – Determination of dimensional change in washing and drying, International Organization for Standardization