Thermal comfort levels and abrasion resistance of protective denim motorcycle clothing

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Abstract

In the last twenty years there has been an emergence of a new class of motorcycle apparel, often referred to as protective denim. Its construction is a denim outer fabric with an inner protective liner fabric made from high performance fibres such as those made from aramids, ultra high molecular weight polyethylene (PE) and aromatic polyester liquid crystal polymer (LCP). These garments should have suitable thermal comfort levels off the bike while providing a high level of abrasion protection to be successfully adopted by riders.

This work used a thermal sweating hotplate and a CE standard impact abrasion test method to evaluate a number of protective denim products. It analysed the thermal resistance of the product in both dry and wet (sweating) modes and compared them with their resistance to abrasion. It compared the four main protective layer types used in protective denim; a woven aramid, a double jersey knitted aramid, a terry loop knitted aramid/PE and a rib knitted LCP. The last two of these products displayed EN 13595-1 level 2 protection labels whereas the remainder had no manufacturer specified abrasion resistance.

The mass per unit area of fabric between the skin and the abrasion surface was directly proportional to abrasion resistance. The woven and double jersey products failed to reach the EN 13595-1 level 1 abrasion resistance but were closer to denim in thermal comfort due to their thinness. The terry loop knit fabric performed far better than the rib knit LCP fabric in both abrasion and thermal comfort. The poor thermal performance of the LCP product was due to the complex spacer fabric arrangement employed around the protective liner.

Introduction

Motorcycle use in Australia has been increasing steadily over the last 10 years with a 43% increase seen in motorcycle sales from 2003 until 2011. One of the markets exhibiting rapid growth was scooters and light commuter motorcycles with 176% growth over the 2003-2011 period (FCAI, 2012). As motorcycle use increases so do the number of crashes recorded. There has been a 14% increase in hospital admissions and 36% increase in emergency department presentations in Victoria alone for on-road motorcyclists between 2003 and 2011 (Cassell, Clapperton, O'Hare, & Congiu, 2006) at the same time as there was a 48% increase in new, on-road bike sales (FCAI, 2012). A similar trend was observed in Queensland where a 100% increase in crashes was seen for mopeds and scooters and a 16% increase for motorcycles over the 2003/4 to 2007/8 study period (Blackman & Haworth, 2013). This increase in motorcycle crashes is attributed to the increased number of registered on-road motorcyclists. While the crash rates per motorcycle and kilometre travelled have fallen over the same study period, the total number of fatalities relative to all road user fatalities has risen dramatically from around 12% in 2003 to 18% 2013. The average rate per 100,000 population has not changed over the past decade. The number of total motorcycle fatalities rose from 188 in 2003 to a high of 245 in 2008 and recently fell to a steady level at 223 in 2012 and then 213 in 2013 (Bambach, Grzebieta, Tebecis, & Friswell, 2012). The national road safety strategy is based on a Safe System Approach which in turn is based on Vision Zero concepts (zero deaths). Hence, this level of rise in fatalities relative to other road users is unacceptable and requires addressing. An earlier study in New South Wales found that the average injury cost for a motorcycle casualty ($99,381) was almost double that of a road casualty ($52,817) (de Rome & Stanford, 2003). Due to the age of this data the actual difference in cost may have changed significantly as there has been large changes in motor vehicle cabin safety levels over this time while there have only been moderate improvements in motorcycle clothing protection and adoption levels. The use of effective personal protective clothing has been shown to reduce motorcycle injury cost and with effective design can be used to reduce the severity of motorcycle injuries (de Rome et al., 2011).

European studies have shown that 75% of motorcycle crashes happen at or below 50km/hr (ACEM, 2004). In motorcycle crashes, the leg is the most frequently injured part of the body with between 70-80% of motorcycle crashes involving a leg injury as opposed to 56% for arm and 30-40% for hand and feet/ankles (de Rome, 2006). A large number of the injuries sustained are grazing or gravel rash from sliding or rolling along the ground. These injuries can be minimised or avoided by the correct placement of effective protective elements within the clothing of the rider.

Leg protection for riders has traditionally been performed with leather pants or one piece leather riding suits however anecdotal evidence from motorcycle apparel shops in Australia show the protective denim range now maintains five times or more floor-space than the leather pants. The thermal comfort, flexibility, convenience and look of the denim product are believed to have enabled it to take this level of market share.

Protective denim is a term used for a multilayer composite textile garment. The garment is normally constructed of two or more fabric layers with the outer layer made of a common apparel fabric (such as denim) and one of the inner layers made of a highly abrasion resistant fabric. Quite often a mesh fabric designed for next to skin comfort is employed as the inner most layer. The type of abrasion resistant fabric varies from product to product with four distinct fabric types used; woven aramid, double jersey (DJ) knitted aramid, loop knitted aramid and rib knitted aromatic polyester liquid crystal polymer (LCP). Little information is provided by the manufacturers on the protection offered by each of these materials. Previous work has shown the method of construction fabric thickness and fibre type have a significant impact on the abrasion resistance of these protective liner fabrics (Hurren, Phillips, & Wang, 2014). Both woven and double jersey knitted fabrics perform at the lower end of protection levels with only loop knitted aramid and rib knitted LCP products achieving abrasion resistance enabling them to qualify for CE Level 1 or higher certification.

Of the high performance fibres available aramid is the most common utilised for protective liners. The most used aramid type is para-aramid, labeled under the trade name of Kevlar® or Twaron®. Para-aramid fibre has high tenacity, resistance to fire and does not melt. These properties are important in a protective liner providing resistant to bursting on impact and helping to avoid melting during heat buildup from abrasion. LCP is very similar in properties to para-aramid. It is marketed under the trade name of Vectran® and is more expensive than para-aramid and this has limited its use in protective layers to currently only one manufacturer. Ultra high molecular weight polyethylene fibres (UHMWPE) have up to 40% higher tenacity than aramid and LCP fibres and are sometimes found as a blend in protective layer fabrics. UHMWPE suffers from strength loss at temperatures above 100°C and has a melting point between 130-180°C so this currently limits it use as a pure fibre type protective liner. It is used as a blend within some aramid rich protective liners to improve fabric breaking and burst strength.

Fabric construction method and structure of the protective layer differs from product to product. Woven protective layers are thin with low stretch due to the way that the high tenacity yarns travel along the length and width of the fabric. Knitted fabrics have a higher stretch due to the yarn stitch loop being able to deform in one or more directions. Knit structures such as double jersey, rib, terry and loop knit are relatively thick due to the 3D placement of the yarn when compared with a single jersey knit or woven fabric from the same yarn. Thickness of the structure is important as the amount of material between the moving surface and the skin is directly related to abrasion resistance (Hurren et al., 2014).

The thermal comfort of a protective denim is important as the product is designed to be worn all day both on and off the motorcycle. The protective layer is normally a thick synthetic fabric attached to the inside of the denim. Synthetic materials can have poor next to skin comfort due to their reduced moisture adsorption. The extra thickness of the product may cause heat retention and discomfort to the wearer. An effective way of measuring thermal comfort is by using a sweating thermal hot plate. The fabric can be measured in both dry and moisture transmission states to accurately quantify its ability to loose or retain heat and manage body generated moisture.

The most accepted method for measuring resistance to abrasion in a motorcycle fabric is by impact abrasion testing (Hurren et al., 2014; Woods, 1996a). Impact abrasion testing has had significant correlation with simulated and emergency department accident damage (Woods, 1996b) and is the test method used by the CE standard accreditation of motorcycle clothing (EN 13634:2010). Only anecdotal or subjective information has been published on the abrasion resistance of protective denim with different protective layers in reference to thermal comfort.

This study has used a sweating thermal hotplate and an impact abrasion tester to evaluate the thermal comfort and abrasion resistance of a number of protective denim products. It discusses the effect of protective layer structure, fibre type and thickness on thermal comfort and resistance to abrasion. These results help to quantify the thermal comfort of the main protective liner types and may be used as a guide for selection of the appropriate level of protection and comfort by a consumer.

Experimental

Materials

All fabric samples used in this report were collected from purchased garments. The samples consisted of a 234g/m^2 twill weave p-aramid fabric removed from a lined denim pant, a 230g/m^2 double jersey (DJ) knit p-aramid fabric removed from a lined denim pant, a 509g/m^2 1x1 rib knit aromatic polyester liquid crystal polymer (LCP) fabric removed from a lined denim pant and a 398g/m^2 un-brushed terry knit p-aramid/ultrahigh molecular weight polyethylene (PE) fabric removed from a lined denim pant. The outer denim layer used for the controlled abrasion and thermal measurements had a fabric mass of 470g/m^2 and a thickness of 1.01mm. The rib knit LCP and the terry loop knit products displayed EN 13595-1 level 2 protection labels whereas the other two garments had no manufacturer specified abrasion resistance.

Abrasion testing

Abrasion testing was conducted on a LAB belt abrasion tester (Mesdan laboratories, Italy) according to EN13595-1. Three samples were cut into 160mm diameter, tested and the mean value calculated. All samples were removed from the garments so that they did not include pockets, Velcro, trim or embellishments. All samples were tested with their original outer denim fabric and any internal mesh or spacer fabrics in place as received. Thickness measurements were conducted using a digital thickness tester (Mesdan Laboratories, Italy) on the same as received structure. The pressure used was 0.5kPa and each sample was measured five times. Fabric mass per unit area was measured for each individual layer using a 230/100mm^2 circle cutter (James Heal, UK) with three samples measured for each fabric. Fabric mass of the protective layer was done using a 100mm square sample cut by hand. The total mass of the structure was then calculated by summing the mass value of each layer. Controlled abrasion measurements were conducted using the same denim outer layer to avoid differences caused by the thickness and quality of the denim fabric. These were measured using the same method as that given above.

Thermal testing

Thermal testing was conducted on a YG606H sweating guarded hotplate (Ningbo Textile Instrument Factory, China). Samples were cut into 360mm squares and layered onto the thermal hotplate with the protective layer against the hotplate (skin) and with a denim outer layer. The same denim fabric was used for all protective layer combinations to avoid differences caused by the change in denim mass and structure. The internal mesh fabric was omitted from all samples where the original had an internal mesh fabric however the LCP had its internal and external spacer fabrics attached during measurement as these are part of the protective mechanism of the fabric. Thermal testing in dry mode was conducted at 20°C and 65% humidity. Each sample was measured twice and the average value reported.

Results and Discussion

Figure 1 shows the structural differences of each of the fabric used in this study. The double jersey and terry loop fabrics have been shown folded so that both sides of the structure can be viewed. The terry loop (3.89mm) and the rib knit (7.22mm) structures were both significantly thicker than the woven (2.1mm) and knitted (2.27mm) protective layers. This is also indicated by the fabric mass with the woven (230g/m^2) and double jersey (230g/m^2) fabrics almost half the weight of the loop (430g/m^2) and over half the weight per unit area of the rib knit (510g/m^2). It would be expected that both of the thicker structures would retain more heat due to this increased capacity of entrapped air.

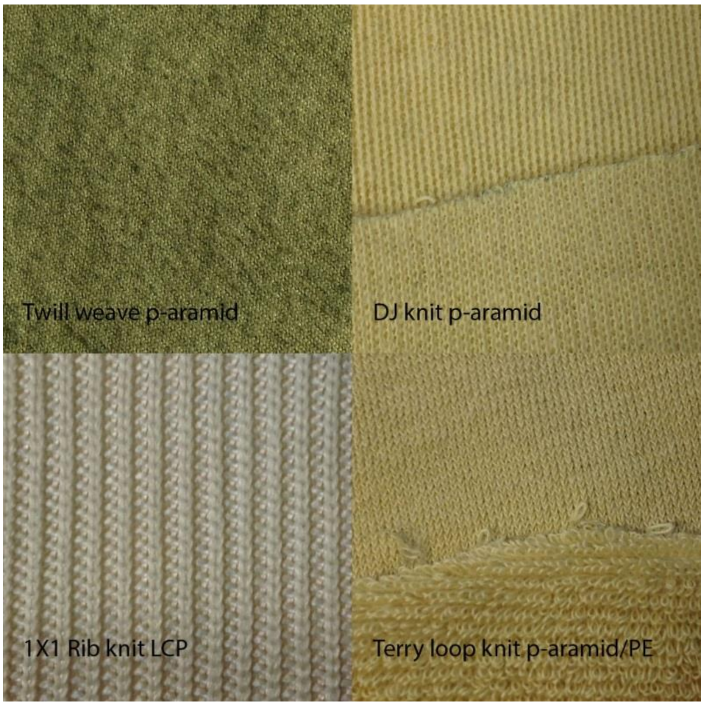

Figure 1. Protective layer fabric structure

As observed in a previous study (Hurren et al., 2014) the woven fabric had the poorest resistance to abrasion (figure 2). The DJ fabric performed better even though it had the same fabric mass per unit area and this can be explained by the failure mechanism that occurs between the fabric structure and the abrasion surface. The woven fabric has point abrasion with the abrasion surface whereas the knit has a longer side contact area. Both the rib knit LCP and the terry loop knit performed well in abrasion but this was expected as they both carried EN 13595-1 level 2 certification. The abrasion resistance of each of the protective layers under a constant denim outer fabric were not that dissimilar to those observed under the as manufactured denim. The only protective layer showing any significant difference was the woven twill that increased in abrasion resistance by 15% as the control denim was of better quality and higher thickness than the as manufactured denim.

The linear regression line is the relationship between the composite fabric mass and the abrasion resistance. This relationship is not strong due to the structural influences of protective layer on the abrasion resistance however there is a general trend that is mirrored by the fabric thickness. The rib knit LCP performs poorly for abrasion with reference to thickness and mass as over 60% of the fabric mass and 70% of the fabric thickness is made up of low protection value fabrics.

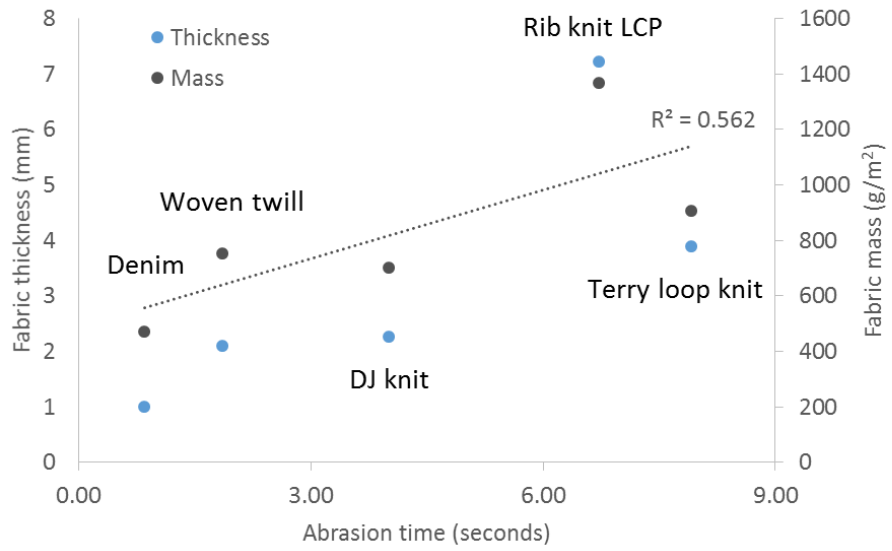

Figure 2. Protective layer abrasion resistance

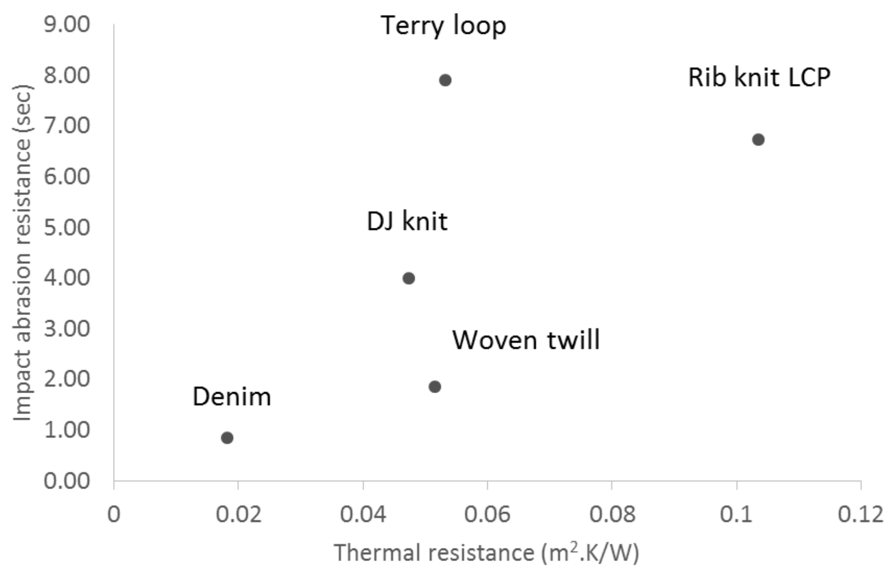

Figure 3. Dry thermal resistance with respect to abrasion time

Dry thermal resistance values measured (figure 3) were not what was expected with the heavier terry loop knit product performing at a similar level to the DJ knit and the twill woven fabrics. An explanation for these findings is yet to be determined as the total thickness of the denim/protective layer is significantly thicker for the loop knit (3.89mm) when compared to the woven (2.10mm) and DJ knit (2.27mm) fabrics. The entrapped air in the loop structure should retain heat however this may be overcome by the thermal conductivity through the p-aramid fibre. The rib knit LCP structure performed significantly worse in dry thermal resistance and this can be directly attributed to the entrapped air in the spacer fabrics and protective layer. The spacer fabrics used by the manufacturer possibly to dampen the impact on the protective layer or body are quite thick with the entire denim/protective layer structure measuring 7.22mm.

The fabric composites tested for thermal and moisture vapour transmission were the same as those supplied from the manufacturer however in the case of the rib knit LCP and the terry loop knit the internal mesh fabric was omitted. In the thermal testing results these very thin (0.4mm) mesh layers would have only marginally increased the thermal resistance and would have had limited effect on the moisture vapour transmission. They were omitted so that all fabrics were measured with the same outer layer of denim and then the different inner protective layer/s so that results were directly comparable.

Dry thermal resistance is indicative of the thermal heat loss or retention of a non-sweating body. These values can be used to approximate how much heat will be retained in a body that is in a comfortable state such as an air conditioned office or restaurant. The dry thermal measurement does not take into account the heat transfer that can occur with moisture transport through a fabric. In a hot environment poor moisture transport through a fabric will result in sweat build up between the skin and the layer of fabric that has the poor moisture vapour transmission. Eventually the wearer will feel both hot and uncomfortable as heat is retained in the moisture and the wet feeling against the skin is unpleasant. To accurately determine the comfort of a fabric in a hot environment then the pressure acting against moisture vapour transmission must be measured. Fabric structure, thickness and fibre type play a significant part in the pressure required for moisture travel. A low moisture vapour transmission value fabric will be more comfortable for a sweating wearer than a high value.

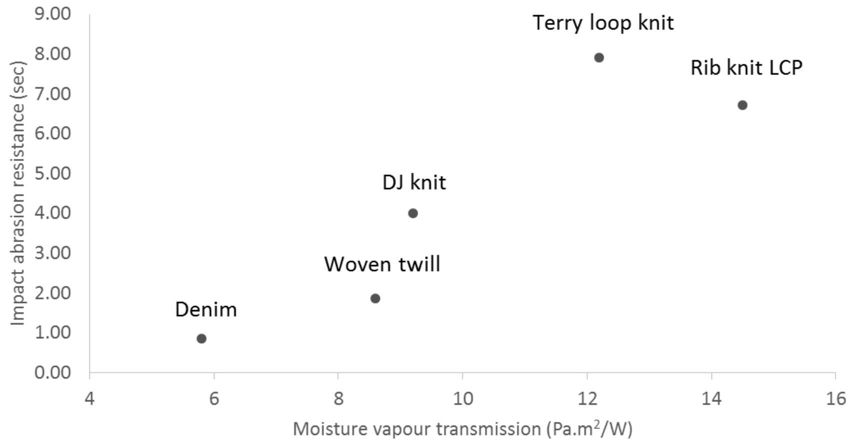

Figure 4. Moisture vapour transmission of protective denim composite fabrics

The moisture vapour transmission rates were similar to the thermal transmission rates for the protective denim composites (figure 4). The only exception was the terry loop knit which performed closer to the rib knit LCP than the thinner fabrics. This was expected as the deneness of the p-aramid terry loop knit structure would reduce water vapour transmission. These results show that the woven twill and DJ knit would be more comfortable to wear in a very hot environment where the wearer is perspiring heavily. If the moisture vapour transmission rate could be improved then the loop knit structure would have significant advantages over the other protective layers due to its high performance in abrasion resistance. Of the two CE level 2 approved products the terry loop knit performed significantly better in all tests.

Conclusions

As abrasion resistance of a protective denim composite fabric is increased, the thermal comfort is decreased. Use of the correct protective layer can minimise this thermal discomfort however current protective fabric technology will result in some level of thermal discomfort for the rider in hot conditions. The terry loop knitted protective layer performed better than all of the other products tested in this work for abrasion resistance and was only marginally worse than the two thinner layers in dry thermal resistance.

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