Motorcycle clothing fabric burst failure during high speed impact with an abrasive surface

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Abstract

High energy is involved when a rider impacts a road surface in a crash. Rider speed, height of fall and road surface morphology all contribute to the level of initial impact energy. Impact can cause fabrics and seams of protective garments to burst rendering their protective value void. The Cambridge abrasion tester tests protective clothing with a fall height of 50mm and abrasive belt speed of 28km/hr, far below what can happen in a "high side" motorcycle crash at 100km/hr. This work addresses the mechanics of what occurs in the first few microseconds of an impact and provides insight into the effect that speed has on fabric burst.

This work used a Cambridge impact abrasion test to evaluate two different protective motorcycle clothing fabrics (a denim and brushed fleecy fabric over a p-aramid protective liner). It measured their abrasion resistance at an abrasion speed of 28km/hr and standard impact height. It used a high speed camera to measure the impact displacement of the test head.

Fabrics with high stretch were more prone to burst failure on initial impact. Fabric burst is caused by a high speed tensile stress between the fabric coupled with the abrasion surface and the inertia of the body dragging against it. Stretch fabrics are pushed into the abrasion surface for a longer period by the body before the tensile stress occurs so the coupling force is higher. If the transition to abrasion occurs early in the impact then a fabric is less likely to burst.

Introduction

European studies have shown that 75% of motorcycle crashes happen at or below 50km/hr (ACEM, 2004). A large number of the injuries sustained are grazing or gravel rash from sliding or rolling along the ground (de Rome, 2006). 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). Previous work has shown the method of construction fabric thickness and fibre type have a significant impact on the abrasion resistance of protective apparel fabrics (Hurren, Phillips, & Wang, 2014).

The most accepted method for measuring resistance to abrasion in a motorcycle fabric is by the Cambridge type impact abrasion testing (Hurren et al., 2014; Woods, 1996a). Impact abrasion testing has had 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). Burst and subsequent instant failure of some fabrics has often been observed when they contact with the abrasion belt. Fabric burst is not unusual and has been observed in many accident situations however the reasons for fabric burst during impact abrasion testing warrants further investigation

This study has used a high speed camera to understand the mechanics of impact that occur when a fabric coated surface is dropped onto a 60 grit sand paper surface. It proposes a hypothesis for burst failure due to impact mechanism and this may be used to design safer motorcycle clothing.

Method

The fabrics used in this research where a 400g/m^2 woven cotton denim and a 380g/m^2 knitted polyester/cotton brushed fleecy fabric in combination with a 440g/m^2 loop knitted p-aramid protective liner.

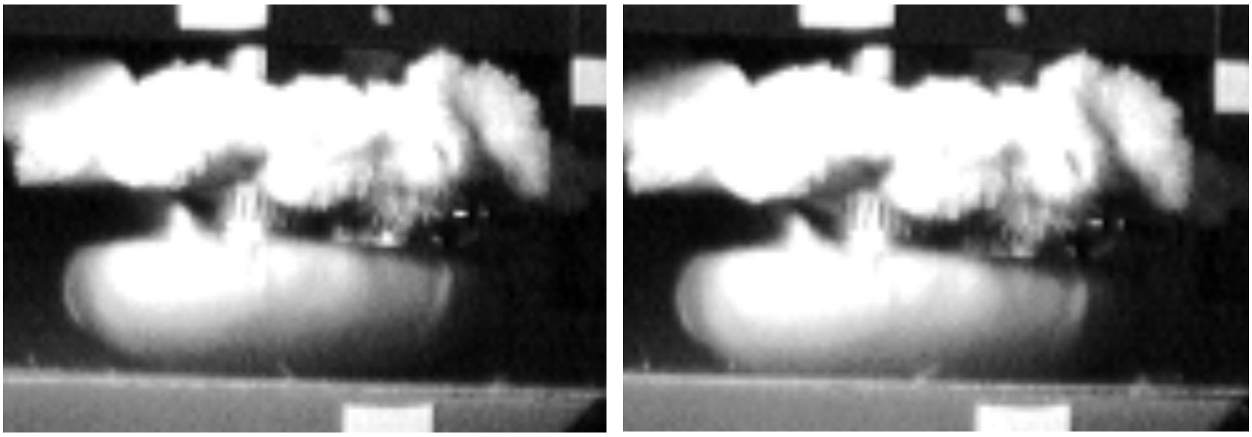
Impact abrasion testing was conducted on a Cambridge style impact abrasion tester (Mesdan laboratories, Italy) according to EN13595-1. Samples were cut into 160mm diameter and clamped to the test head using a spiral lock clamp. The samples were placed so that they had an outer denim fabric and internal abrasion resistant fabric. Six test samples were conducted for each fabric type.

For high speed camera measurement the fabrics were placed on the abrasion head and then dropped onto the test belt from 50mm with the test belt off. High speed images at 2000 frames per second were captured using a MotionScope PCI 2000S monochromatic camera (Redlake, Germany). Lighting was provided by two 500W quartz halogen stand lights. The displacement of the test head was measured using the distance between the top left hand corner of the white reference marker on the sample mounting frame (right hand side of abrasion sample) and the same reference point on the white marker below the abrasion sample. High speed camera images were used to create the displacement versus time curve to understand the gripping forces operating on the fabric.

Stretch and elongation at break tests were performed on a 5967 Materials Testing System (Instron Corporation, USA) equipped with a 1000 N load cell. The test gauge length was 100mm with samples frayed to have a 50mm width and 5mm frayed edge on each side. Both breaking force and elongation at break were conducted at 100mm/min extension rate. Five samples of the warp and weft were measured for each fabric type.

Results and Discussion

The time from the point of first contact with the abrasion surface to point of maximum force being applied to the fabric against the abrasion surface is dependant on the thickness and compressability of the fabric, the impact mass and the height of impact. In these initial experiments the impact height and mass were kept constant and only the fabric varied. Figure 1 shows the images of impact for a denim fabric covering two protective loop knitted aramid layers. The first image (a) is the point where the fabric first engages with the abrasion belt and the second image (b) is taken 6.5ms later at maximum downward displacement of the impact surface.



(a) (b)

Figure 1. Abrasion sample in initial contact (a) and at maximum downward displacement (b)

Analysis of these high speed images produced a displacement versus time curve that enabled a better understanding of the dynamics occuring in the impact (figure 2). As the sample impacts the surface the force pushing the fabric into the surface increases to a maximum point before reducing again as the body bounces off the surface. There was some hysterisis then observed with a second fabric compression before coming to equilibriam at a final compression level. The maximum downward displacement and subsequent impact force was achieved in the initial impact displacement. For burst to occur the fabric must grip with the abrasion surface and a tensile force is then applied between the clamp and the abrasion surface. Once slip of the fabric on the abrasion surface occurs the tensile force applied is significantly reduced. The point of change from grip to slip is then very important for the burst resistance of a fabric.

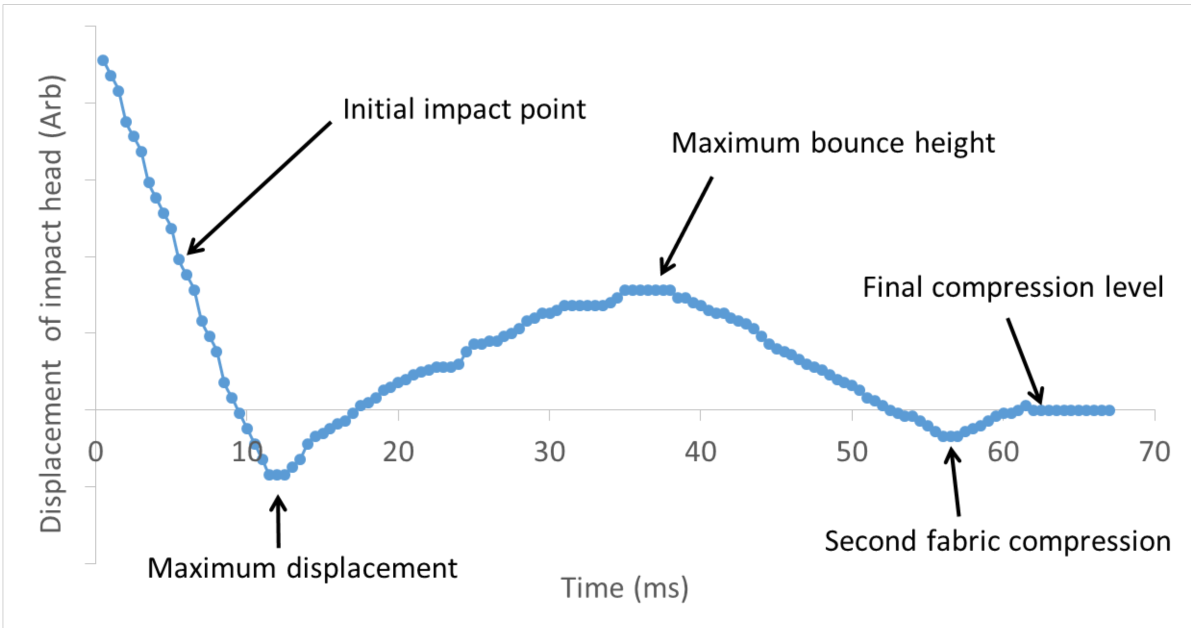


Figure 2. Impact displacement curve for stationary abrasion belt

To understand the mechanism of burst, the stretch of the fabric must be considered as this will alter the point of grip to slip transition. The stretch of a low stretch denim fabric was 20% at break. The gauge length of the abrasion tester was 30mm between the test head and the impact surface. There would need to be greater than 6mm extension of fabric when impacting with the moving belt for burst to occur in the test setup. At 8m/s (28.8km/hr) abrasion surface speed it would require the fabric to be in contact with the abrasion surface for 0.75ms before it would extend 6mm (maximum extension). If the transition from grip to slip has not occurred by this displacement then burst will occur. When this transition to abrasion time was placed on the impact displacement curve (figure 3) the amount of grip force would be low as the impact pressure is only slightly acting on griping the fabric with the abrasion surface. With a low gripping force the fabric would be expected to transition from grip to slip without bursting (as observed in abrasion trials). If the speed was increased to 28m/s (100.8km/hr) the gripping force would reduce making burst on impact less likely. If the speed is reduced then the gripping force is increased contrary to common belief.

With the protective hoodie fabric the extension was 130% at break. The impact displacement curve for the protective hoodie was similar to that of the protective denim so only the protective denim curve was used to explain the findings. There would need to be 39mm extension of fabric for burst to occur. At 8m/s belt speed it would take 4.9ms for the fabric to extend this distance before it went from grip to slip. This would result in a significantly higher grip level occurring before the change from grip to slip could occur. The grip with the abrasion surface could be high enough to enable a tensile failure to occur in the fabric (for this fabric burst was observed in abrasion testing). At 4m/s (14.4km/hr) the impact force was reducing as the body had bounced on impact but burst was still observed.

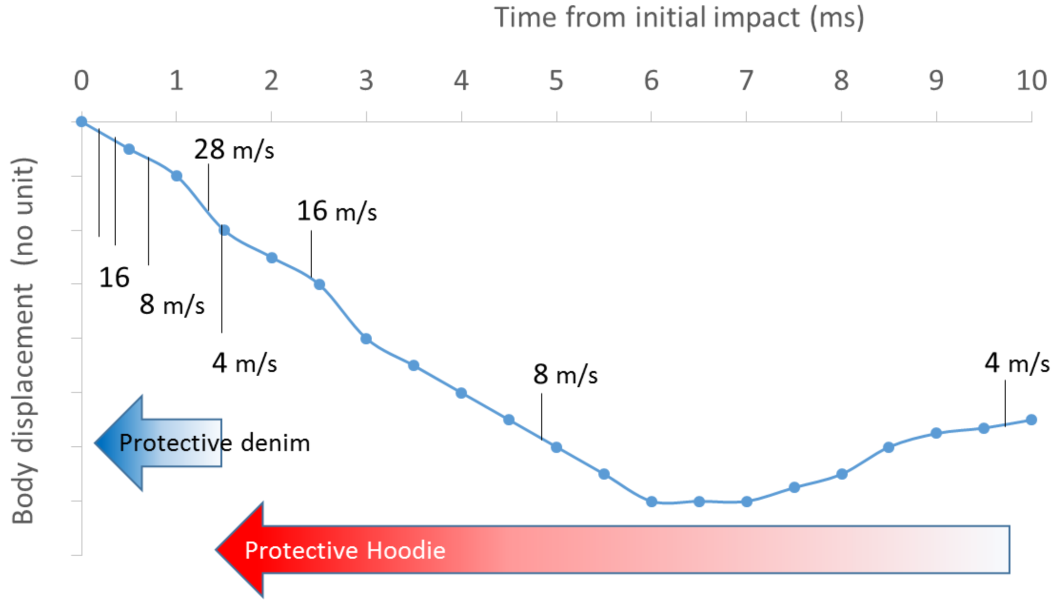


Figure 3. Impact displacement curve with maximum extension before burst points highlighted for protective hoddie (above the line) and protective denim (below the line)

Conclusions

The force applied to a fabric during impact abrasion is dependent on the abrasion surface speed, impact height and weight. For burst to occur the fabric must be pushed into the abrasion surface to provide an effective grip to enable tensile forces high enough to cause tensile failure (burst). The level of stretch of the fabric allows it to extend the time before high tensile loading into a region of maximum grip with the abrasion surface. High stretch fabrics need to have higher fabric strengths to resist burst or they will be prone to burst on impact. Lower speed impacts with an abrasion surface are more likely to induce burst failure than high speed impacts. Further impact abrasion testing at different abrasion surface speeds is still required to confirm this hypothesis. These results will be important in the design of burst resistant protective fabrics for both motorcyclists and bicyclists.

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