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IMPACT PROTECTION FOR FUNCTIONAL APPAREL

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ABSTRACT

Whilst good impact protection using materials of 5-10 mm thickness can be achieved, the thickness of the resulting assemblage often creates difficulties of appearance, stiffness and loss of comfort. This creates problems for product developers and users. In the quest for efficient impact protection using thinner materials, research has been directed to understanding the mechanisms that provide protection. This has led to the adoption of a biomimetic approach, with consideration being given to composite materials. The research reported concerns the ability of composites to enhance impact protection without being bulky.

The materials under investigation in this research are primarily commercially available in a variety of thicknesses and densities. The composites have been formed using double-sided adhesive tape. The testing work is undertaken using a customised rig that allows the forces and timescales of impacts to be recorded.

The performances of the composites are compared with the test results of a variety of alternative materials, and conclusions are drawn about the mechanisms of achieving enhanced protection. Design principles are identified to assist the designers and product developers of functional apparel.

KEYWORDS:
Impact protection, functional apparel, biomimetics, clothing comfort

INTRODUCTION

The research reported in this paper is concerned with materials and garments that can reduce injuries associated with impacts due to collisions, falls and violent behaviour. To demonstrate the relevance of this topic, attention is drawn to data analysed by Safe Kids Worldwide (Healy 2013; Ferguson et al. 2013). Their report relates to a database in the U.S. known as the National Electronic Injury Surveillance System. They found that in 2012, 1.35 million young people (aged 6-19) were seen in emergency rooms for sports-related injuries. Findings for the previous year were very similar. High on the list of problems were sprains and strains, fractures, contusions, abrasions and concussions and the estimated cost of these injuries was more than $935 million per year.

Alongside these data for young people can be placed statistics for adult team sports injuries, many of which are caused by high-energy impacts. Significant problems are experienced in contact sports such as rugby, soccer, American football, boxing, ice hockey, field hockey, cycling, skiing, snowboarding and baseball. These sports bring to the fore the competitive instincts of players, and injuries are inevitable when individuals are operating at the limits of their physical performance.

It is widely recognised that the severity of injuries can be reduced with appropriate training and also by the use of appropriate protective clothing. Some materials are able to lessen the effects of an impact by absorbing energy or dissipating the force so that the peak forces experienced are reduced. High performance materials are embedded in the garment in locations likely to experience impacts. These materials need to be soft, thin, flexible and durable. Further discussion of these issues is provided by Venkatraman and Tyler (2015).

Some users have expressed concerns about the way protection is incorporated in the products. For example, garments may have pads inserted into fabric pouches which can move during an impact and are unlikely to remain in position and protect the wearer during a slip or fall or collision. Some garments possess bulky pads, which inhibit the breathability, restrict the free movement of the athlete and affect aesthetic appearance. Other garments appear to have “protection” tacked on, with very little input from designers or product developers. To address these concerns, research has been undertaken to understand the mechanisms of impact protection and to develop design principles for product development.

MATERIALS AND EXPERIMENTAL METHODS

A range of impact-resistant materials were obtained for comparative evaluation. These included some of the branded materials used in competitive sportswear together with leather (as a natural benchmarking material) and a polyvinylnitrile thermoset polymer.

Material	Notes
D3O	Dilatant material
Deflexion S-range	Three-dimensional spacer fabric with silicone
Deflexion TP-range	Dilatant material
EVA foam	Ethyl vinyl acetate foam
Leather	Natural benchmarking material
Poron XRD	Open-cell urethane foam
PVN	Polyvinylnitrile thermoset polymer

These materials were obtained in different thicknesses, ranging from 2mm to over 15 mm.

There are numerous testing scenarios for determining impact resistance. Of these, two standard methods were considered of greatest relevance to apparel-related work. These are: Industrial bump caps (BS EN 812:1997/A1, 2001) and Specification for head protectors for cricketers (BS 7928, 1998). Both involve a striker falling on a surface, with the protective product experiencing the impact. The research reported here focuses on material properties affecting peak forces and impact durations. The experimental equipment detects the forces experienced by a transducer attached to an anvil located under the protective material. A similar method is specified by the International Rugby Board. Their hammer and anvil test involves a flat striking surface (weighing 5kg) falling on to a protective pad which rests on a steel anvil (Pain et al. 2008).

The purpose-built impact attenuation equipment used in this research has a striker, a steel ball, falling on to a flat anvil on which the protective material is placed. The pressure sensors are located below the sample material and the forces transmitted through the material by the impactor are recorded in the form of a load-versus-time data set. By varying the diameter of the ball, different impact profiles can be created. The mass and height of fall parameters determine the impact energy. For research purposes, impacts of 5, 10 and 15 Joules are used. An illustration of the test equipment is shown in Figure 1.

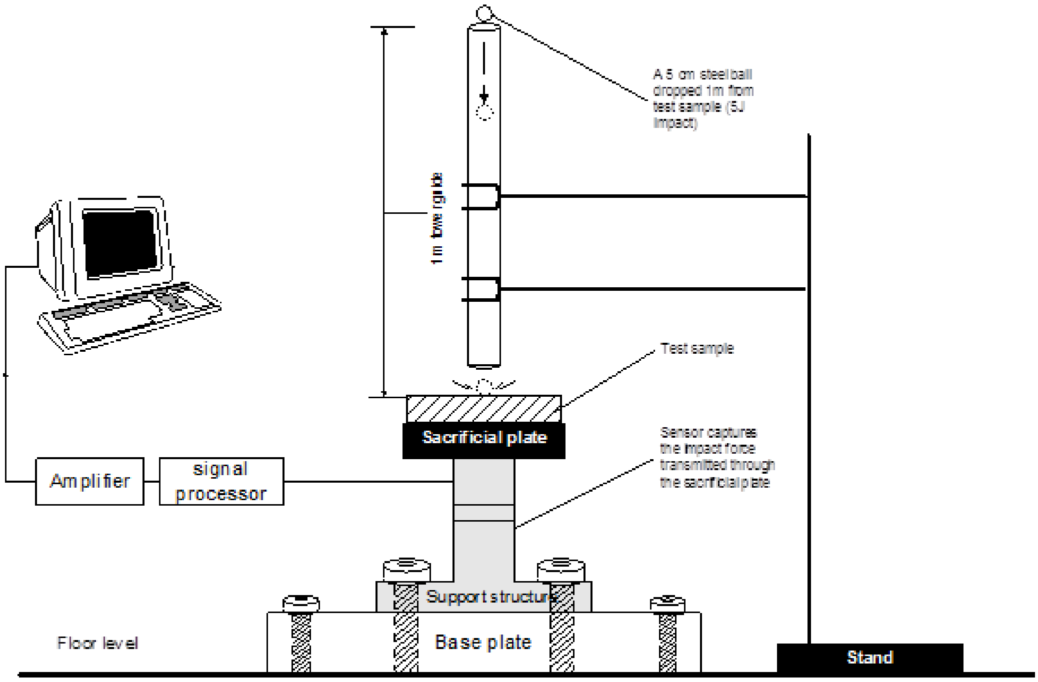

Figure 1. Impact attenuation test rig

Impact forces are experienced by the test material, and the forces reaching the support plate are recorded using a load washer. A typical data set is plotted in Figure 2. With some samples, the ball bounces a few times before coming to rest, but in other cases, often with thicker materials, there is no bounce. From traces like this, the durations of impacts on different thicknesses of materials can be measured.

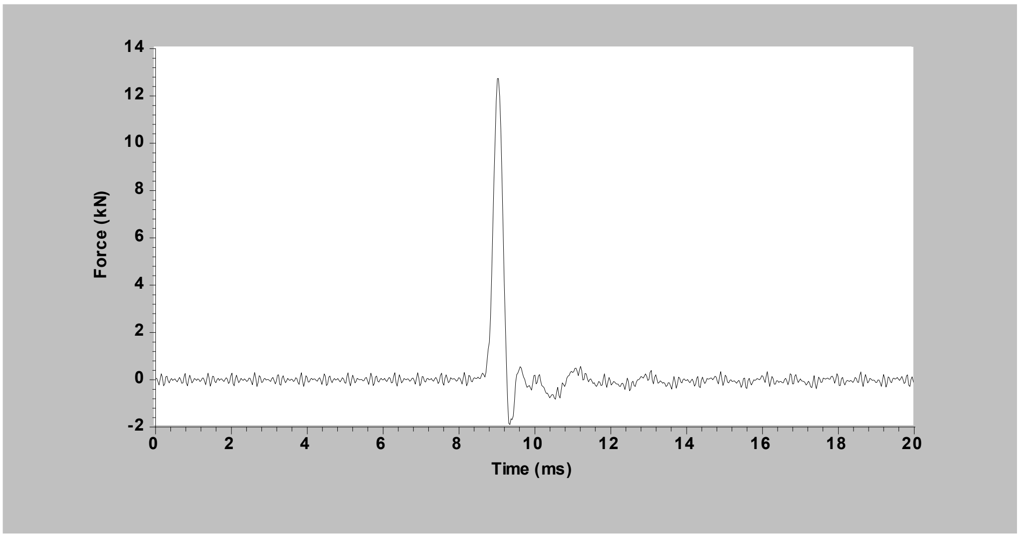

Figure 2. Impact forces experienced with protection provided by 3 mm Poron XRD.

The experimental results reported here give the mean obtained from 5 measurements, with standard deviations being, typically, less than 5% of the means.

RESULTS and DISCUSSION

A selection of commercial materials was tested to compare their abilities to protect against impact. In addition, unfinished leather was tested to provide benchmark values. The rationale is that leather has been used in garments to provide wearers with enhanced protection. Figure 3 presents peak force variations for a range of materials with different thicknesses. Thinner materials experienced higher peak forces. As thicknesses increase, the commercial products designed to absorb energy when impacted reduced peak forces more effectively than the leather sample.

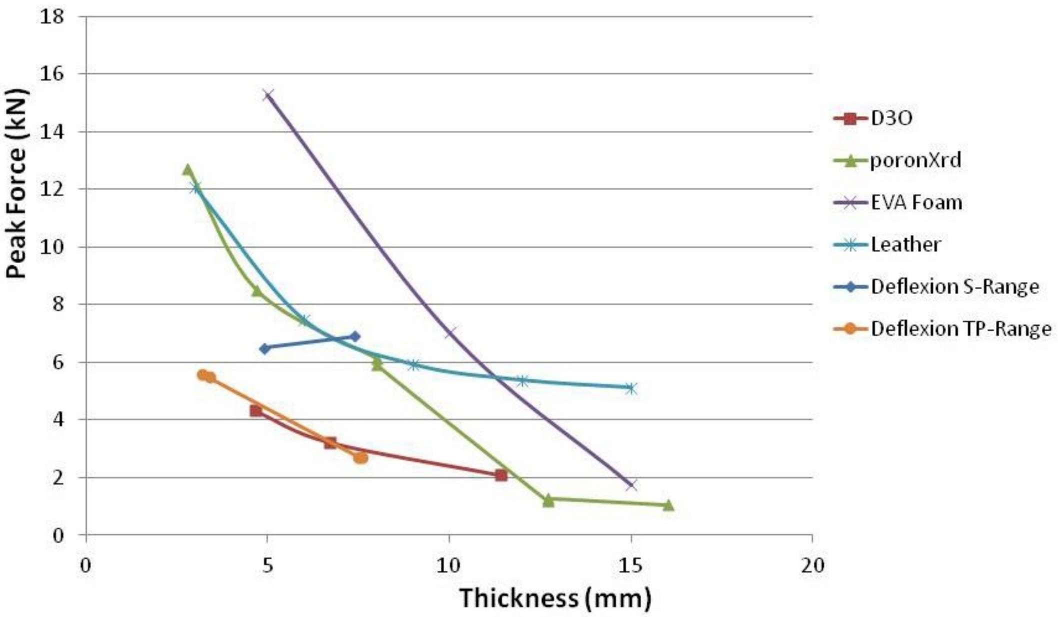

Figure 3. Findings from Impact Attenuation Tests

The EVA foam samples were taken from commercial garments designed for rugby players. Neither the 5 mm (used for arm protection) nor the 10 mm (used for shoulder protection) sample compared favourably with leather. The maximum thickness for shoulder protection permitted by the International Rugby Board is 10 mm. In general, the branded commercial materials performed better than leather, although clear differences between them are apparent below thicknesses of 5 mm.
Above peak forces of 12 kN, damage was caused by the impacting sphere, resulting in a hole through the material.

Whilst energy absorption by the protective material must be a factor, other mechanisms have been identified during this research. Figure 4 presents data plots for 5 Joule impacts on different thicknesses of poronXrd. The vertical axis records the measured force in kN, and the horizontal axis records time in tenths of a millisecond. The impact durations are in the range 2 ms to 10 ms.

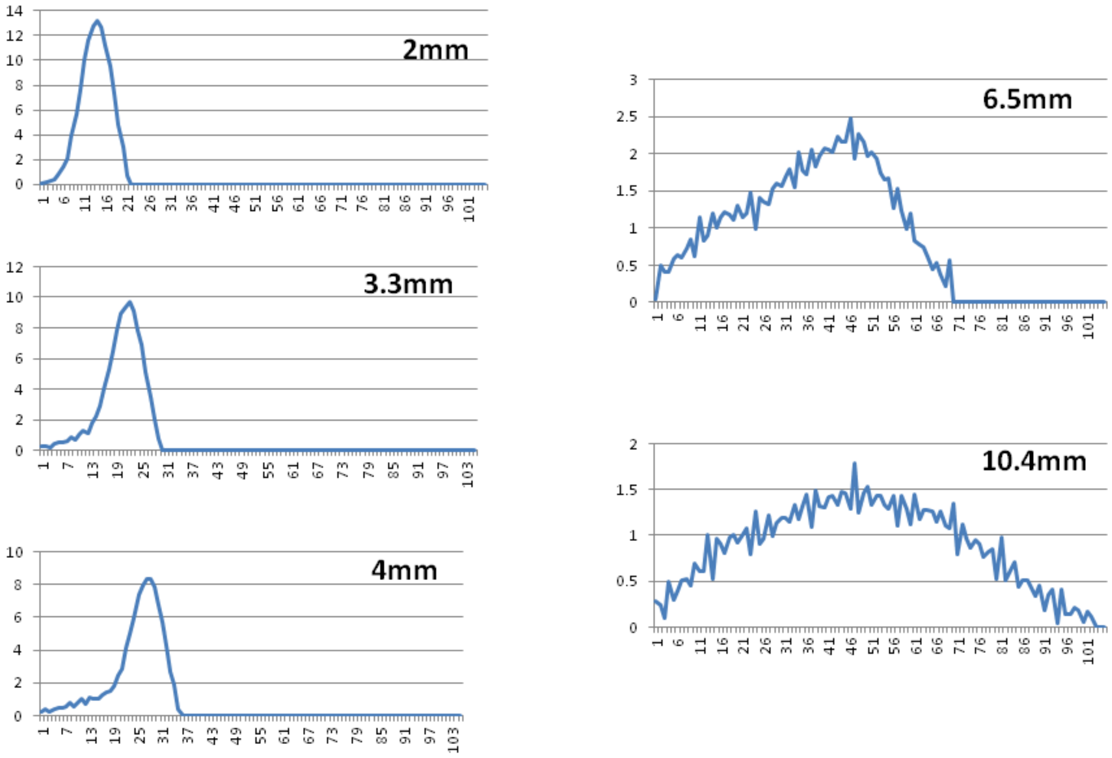

Figure 4. Variation of impact duration with thickness of material (poronXrd)

These test results to show a broadening of the impact force traces resulting from the increasing thickness of a protective material. If energy absorption were the dominant factor, it is expected that the peak forces would reduce with relatively little change in the impact timescale. On the other hand, when the impacting event is experienced over a longer timescale, the material acts as a cushion and, as a consequence, the peak forces must reduce.

A third mechanism for reducing peak forces is to increase the area of material affected by the impact. When a larger area experiences an impacting force, the energy of the impact is more widely distributed and the peak force at any particular location is reduced. As energy is dissipated within the protective material, the test equipment should also record a reduction in the measured forces.

One commercial product that sets out to distribute the energy of an impact over a larger area is isoBLOX^{TM}. This polymeric sheet is about 1mm thick and the manufacturers claim that their product operates by promoting both energy absorption and energy dispersion. Experimental work was undertaken to assess the influence of isoBLOX^{TM} used alongside PVN sheets of different thickness. Peak forces were measured and plotted in Figure 5.

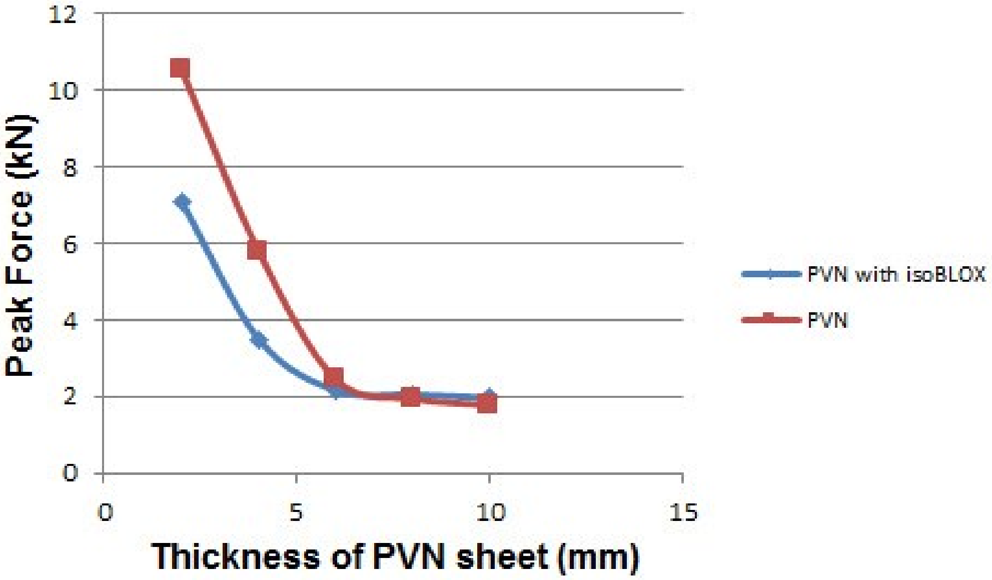

Figure 5. Experimental results obtained with isoBLOX^{TM}

The PVN material provides effective protection above 6mm thickness, and the addition of an isoBLOX^{TM} sheet makes little difference to the performance under these experimental conditions. However, there are distinct differences for the thinner layers of PVN. However, it should be noticed that if the isoBLOX^{TM} curve is shifted to reflect the 1mm thickness of the material, the two curves almost overlap.

One of the aims of this research is to develop thin, flexible materials suitable to imparting impact protection to apparel. Energy absorption has not emerged as a major factor for thin materials. The most important parameter appears to be thickness, and the ability of the material to extend the impact time so that the energy of the impact can be dissipated with less trauma. There are remaining questions about increasing the area of the impact, so that a greater volume of the energy-absorbing material can be involved. To find answers to these questions, a hypothesis can be proposed based on the use of leather as a material providing impact protection.

Leather has been used by mankind for reinforcement and impact protection for at least as long as recorded history. Leather is a composite material, with an outer skin (which is durable) and an inner more porous layer (which acts as a barrier between the skin and the delicate tissues within the body). The biomimetic hypothesis is that the skin is not just a surface, but it has a function of enhancing the protective properties of skin, including energy dispersion.

To test this hypothesis, several composite materials have been prepared. The inner porous layer was chosen to be made of PVN, with nominal thicknesses 2mm and 4.5mm. The surface layer was a fabric or polymer sheet that was attached to the PVN using a double-sided adhesive tape. Selected results are in Figure 6.

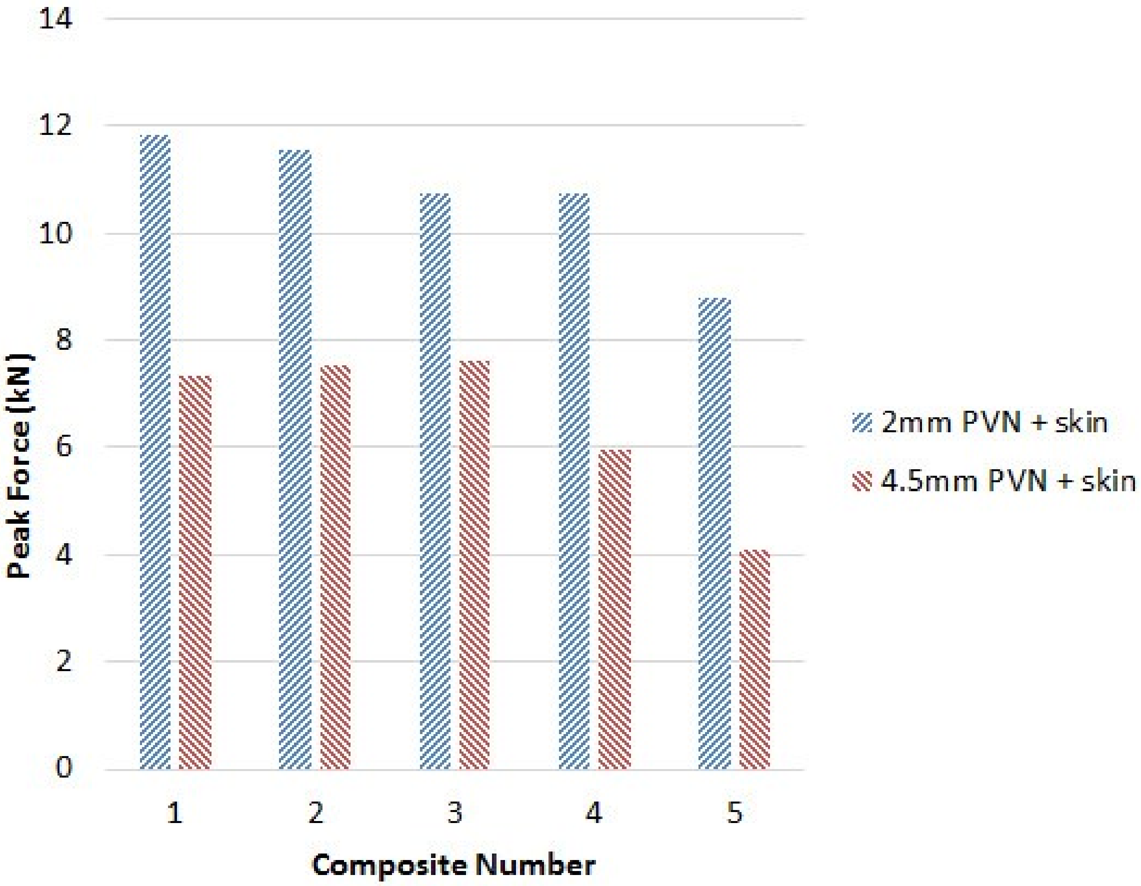

Figure 6. Experimental results using composite materials
Sample 1: PVN sheet only
Sample 2: PVN sheet with 100g Kevlar weave
Sample 3: PVN sheet with black polyester woven lining
Sample 4: PVN sheet with 0.5mm polypropylene film
Sample 5: PVN sheet with nylon/polypropylene mesh

Sample 2 has the covering of Kevlar weave, but there are no indications that the skin has any effect. It was a fairly loose weave, so the implication is that it was inadequate for spreading the area affected by the impact.

Sample 3 is a tightly woven polyester lining, and a small reduction in peak forces is evident with the 2mm substrate. There was a problem her as the surface of the sample was visibly affected, with localised delamination at the point of contact. Figure 7 is an image of the delaminated area. What it shows is that the fabric was dispersing the energy, but the internal cohesion of the composite was inadequate for the task.

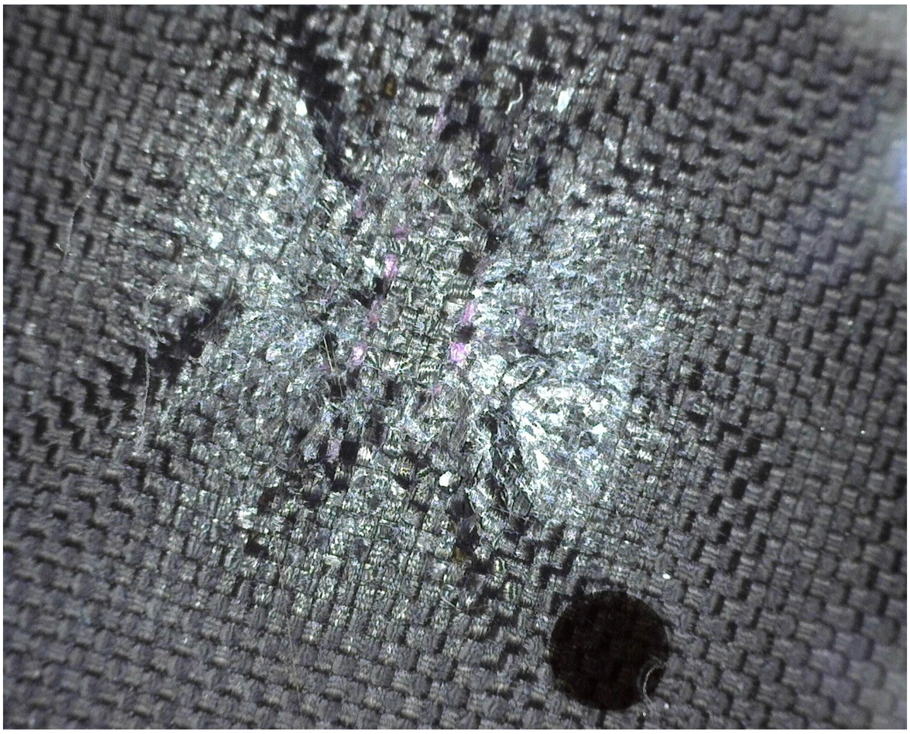

Figure 7. Delaminated polyester lining (The dark circle is 1.5mm diameter)

Sample 4 had a covering of a solid sheet of 0.5mm polypropylene. This was slightly deformed by the impacts, but was anticipated to disperse the impact energy more effectively than a fabric. Reductions in peak force are apparent for both substrate thicknesses.

Sample 5 was covered with a nylon/polypropylene mesh, as illustrated in Figure 8a. This shows peak force reductions of over 30% for both substrates. At the impact location, the mesh was deformed but the substrate showed the least signs of damage of all the samples tested.

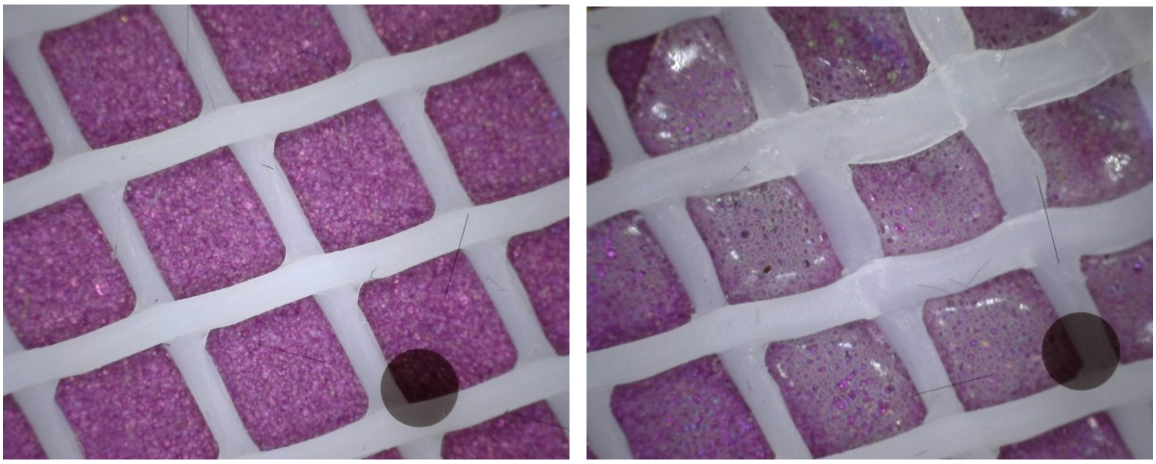

Figure 8. PVN substrate covered with a nylon/polypropylene mesh (The dark circle is 1.5mm diameter) (a) Before the impact. (b) After the impact.

The test results show a diversity of behaviours, but the all are consistent with the hypothesis proposed. The Kevlar and polyester surface coverings were unable to disperse energy over a wider area, in one case because the material was too loosely woven and in the other case because of delamination. The polypropylene sheet had a greater potential to promote dispersion, but the greatest effects were found with the nylon/polypropylene mesh.

CONCLUSIONS

Product developers interested in providing garments with impact protection should realise that there are several mechanisms relevant to their work. This research considers energy absorption by materials, reduction of peak forces transmitted by extending the duration of the impact, and energy dispersion by broadening the area of impact. For apparel, the greatest effects are associated with materials that extend the duration of impacts, but energy dispersion is likely to be an important factor to address. By applying a biomimetic approach, the hypothesis proposed is that the internal structure of leather provides a template for assembling composite materials to protect against impacts. Experimental work with sample composites has demonstrated results consistent with the hypothesis, thus providing a framework for future research.

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