A CRITICAL REVIEW OF IMPACT RESISTANT MATERIALS USED IN SPORTSWEAR CLOTHING

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Abstract

This paper highlights the significance of impact resistant materials which are incorporated in sportswear and functional outdoor applications. In recent years, there have been interesting explorations on a wide range of composite materials such as coir/EVA as nonwoven impact protectors, polypropylene and flax fibre laminate, cellular textile materials as sports protectors for helmets. 3D spacer fabrics were explored by Dow Corning on varying thicknesses and levels of protection. In addition materials such as, D3O and visco-elastic polymer dough were also reported to have potential in sportswear applications such as the market for knee pads. In addition, Dow Corning's helical auxetic system is made up of an inelastic fibre spirally wound around a thicker elastic fibre that expands to absorb the shock while the inelastic one limited the expansion. Some concerns noted by researchers are that it has limited applications and the benefits of the impact resistant materials should be evaluated using precise monitoring systems.

In this context, the authors have critically evaluated the literature, explored the importance of such materials in the context of functional clothing used for sportswear, and reported their limitations and implications. The study also is informed by experimentation using a custom-built measurement device to precisely monitor the pressure profile of various materials. This device is modelled on some of the ISO test procedures for assessing impact protection. The pressure sensors are located below the sample material and forces transmitted through the material by an impactor are recorded in the form of a load-vs-time dataset. Quantitative comparisons of a range of commercial materials used for impact protection have been obtained.

Background and rationale

Recently there has been a surge in the sports wear market for low levels of impact protection particularly in games such as baseball, hockey, football, cricket, etc., and medium level impact protection on functional wear such as personal protection equipment. The main focus of this paper is to highlight the significant importance of impact resistant materials which are incorporated in sportswear and functional outdoor applications. The study disseminates a recent experimentation using a custom-built measurement device to precisely monitor the pressure profile of various materials. This device was modelled on some of the ISO test procedures (BS7928:2009) for assessing impact protection materials.

There has been a considerable amount of literature (Shishoo, 2005) on sportswear products discussing on performance such as comfort, durability, functionality, etc. However there is a shortage of information relating to materials which are used for preventing from injuries sustained in sport related activities. This includes the level of impact or force sustained at the point of contact, capabilities of absorbing the shock without causing injury to the wearer, practicality of use in sportswear apparel and clothing.

In the UK there is a great deal of interest amongst younger adults to get involved in sport or leisure activities. Different sports require different performance characteristics depending upon the level of activity, the intensity of sport played – amateur or professional and whether it is played indoor or outdoor. In recent times there has been an increase in the number of people who involve in sport related activities (recreational, leisure activities). Sport England (formerly known as English Sport Council, 2011) which reported that during April 2010/11 that in the UK 6.9 million adults (above age 16) have had participated in sport activities three times a week for 30 minutes at moderate intensity. This report reveals that the participation increased by 108,600 since 2007/08.

National sports medicine institute, NSMI (www.nsmi.org.uk) stated that several sports players endure injuries that are caused by impact or contact with objects, surfaces or other people. Injuries caused by impact and contact are common sports such as football and rugby and more dangerous sports such as motor racing, boxing and skiing. Often, contact with other people can cause an athlete to become off balance, or change direction quickly; this causes damage to the connective tissue; powerful direct contact may also cause a joint to become displaced. Impact injuries usually include spinal injuries, ligament and tendon damage, fractures and head and spinal injuries. They also added that although injuries are a part and parcel of contact sports; measures if taken appropriately would reduce the likelihood of suffering from an injury. Protective clothing is often worn in more dangerous sports to protect the body from injury; this can often be seen in rugby and boxing. Some of the common injuries in most widely played sport activities are:

Cricket

- Head injuries to batsmen caused by fast bowling
- Bowlers are at risk of back injuries (muscle strains) due to the repetitive and sometimes awkward movements involved when bowling.
- Fieldsmen getting injured during fall or collision.
- Knee damage and strain is also common.

Football

- Fractures
- Cuts and bruises
- Boot-stud injuries
- Knee damage and strain due to repetitive twisting
- Ankle injuries

Racquet Sports

- Tennis elbow
- Fractures caused by falling on hard surfaces
- Muscle strains through repetitious movement
- Frozen Shoulder caused by overhead movements

Impact injuries can damage to the connective tissue, and cause superficial injuries such as cuts, bruises, and most fractures which can be treated with simple medication and will heal over time; however head and spinal injuries should be treated as emergency medical condition.

A range of composite materials such as coir/EVA as nonwoven impact protectors (Maklewska et al., 2005), polypropylene and flax fibre laminate (de Velde et al., 1998), cellular textile materials (Tao and Yu, 2002) as sports protectors for helmets. In addition, 3D spacer fabrics were explored by Dow Corning on varying thicknesses and levels of protection (Dow Corning, 2011). Researchers (Maklewska et al., 2002) compared the impact strength of nonwoven fabric pads intended for applications in protective clothing and sportswear. A Schob pendulum elastometer measured fabric resilience. An Instron tensile testing machine determined changes in deformation in relation to load. The 40 millimetre thick single layer, three-dimensional fabric exhibited a high relative absorption rate and low impact force, but was too thick for use in protective pads. The 20-millimetre thick multilayer fabric was more suitable. Researchers added that future research would address the manufacture of multilayer protective pads with a variety of fabrics having different properties.

Cushioning technology provider Roger Co. have reported two customisable products using its Poron XRD material (WSA, 2011), two versions were highlighted extreme impact pad and B-guard. The X-pad was recommended for knee and elbow pads to shin and thigh protection. The product has fabric backing that allows moisture wicking air channels to enhance comfort.

Table 1 Examples of materials used in sports wear for impact protection

S.No	Name of the material	Source	Relevance	Remarks
1	Sorbothane	Sorbothane.co.uk	Shoe insoles for absorbing shock	A synthetic visco elastic polymer
3	Kryton 10	Gilbertrugby.com	Triflex padding system	Gilbert PE foam
4	Canterbury Flexitop vest,	Body Armour	Impact protection	PE foam
5	Kooga EVX V	Kooga-rugby.com	Pads for a wide range of	Padding EVA (ethyl vinyl

			sportswear	acetate)
6	POC-U		Can be moulded into various shapes	Visco-elastic polymer dough – polyurethane foam
7	Force field body armour	Forcefieldbodyarmour.com		Nitrex EVO A family name for the PVC Nitrile materials used in triangular grid form.

Materials and Methods

Whilst there are many standard test methods, the emphasis is not on materials, but on the efficacy of Personal Protective Equipment (PPE). The driver is safety because commercial products need to achieve a specified level of protection for the wearer. Many of these tests relate to headwear: for industrial working environments and for a wide variety of sporting activities. Two of these tests have informed the design of the test equipment used.

Industrial bump caps

BS EN 812:1997/A1:2001: Industrial bump caps are intended to protect the wearer's head from the effects of bumping against hard, stationary objects with sufficient severity to cause laceration or other superficial injuries. The striker for measuring impact protection is a 5 kg mass with a flat striking face with 10 cm diameter. This falls onto a head form to which the force transducer is attached. The impact energy is nominally 12.5 J and impact protection is related to the maximum force transmitted to the head form. The upper limit for passing the test is 15.0 kN.

Specification for head protectors for cricketers

BS 7928:1998: In this case, the falling head form method is used, because the wearer is anticipated to provide movement that will affect the impact experienced. The head form, with the helmet fitted, is raised above a fixed anvil and dropped to generate the impact. The test equipment incorporates a tri-axial accelerometer to record the deceleration of the head form in all three directions, and a resultant value is recorded. The test data allows the calculation of the head injury criterion (a measure of the expected likelihood of serious injury to the user). The anvil is normally a cricket ball-sized object, but a flat surface or a simulated kerbstone may also be used. The impact energy is normally set to 15 J and the maximum deceleration of the striker is 250g (where $g=9.81m/s^2$)

Both these tests involve a striker falling on a surface, with the protective product experiencing the impacts. As our research concerns material properties, measurement of deceleration are of less interest. Consequently, we have focused attention on the forces experienced by the transducer attached to the anvil which is under the protective material. The test equipment 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-vs-time data set. By varying the diameter of the ball, different impact profiles can be created. The mass/height of fall parameters determines the impact energy. For research purposes, impacts of 5J, 10J and 15J are used. An illustration of the test equipment is in Figure 1.

Table 2 Summary of materials used in this research

Sample number	Material	Thickness (mm)	Density (g/cm3)	Note
1	GPhlex	8.5	0.0025	A proprietary material sourced from collaborator
2	D3O	-		Dilatant material absorbs shock
3	Poran XRD	7.63	0.0005	Open cell urethane foam
4	EVA foam	5.1	0.0003	A cross-linked closed cell polyethylene foam
4	Leather	2.7	0.0008	Unfinished leather (cow)

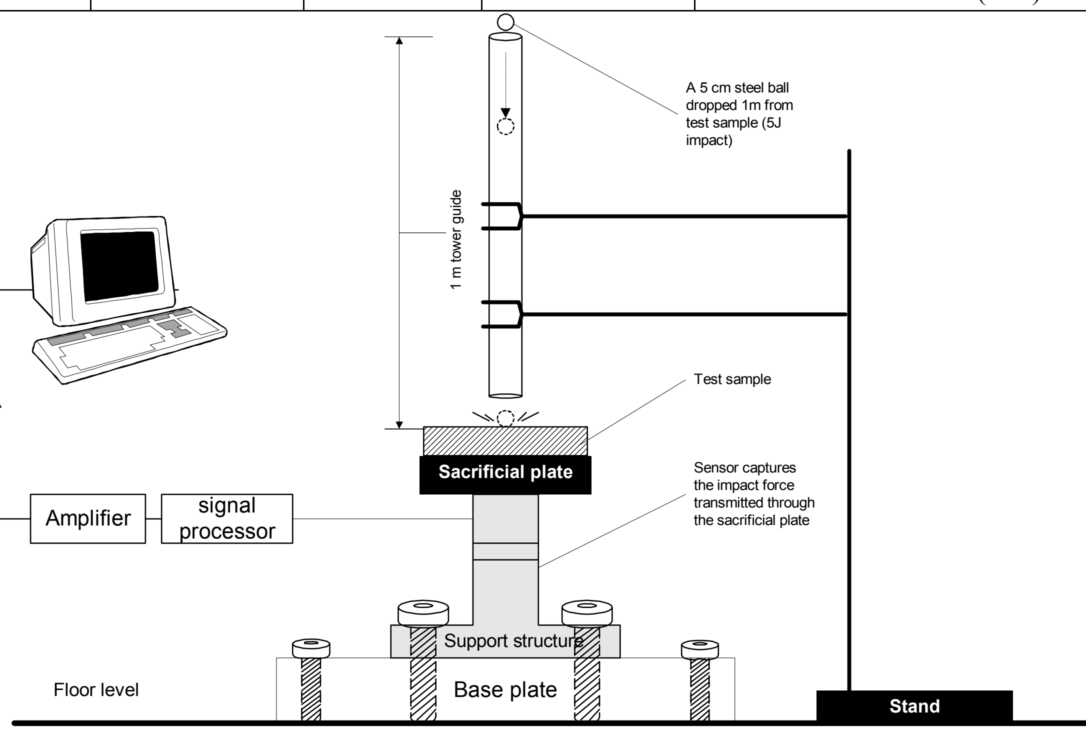

Figure 1 Illustration of impact measuring testing device

In the tests reported here, all the materials received the same low energy 5J impacts. A typical set of results recorded for a thin (3 mm) material is illustrated in Figure 2. There was insufficient energy taken out by the material, so the ball made a few bounces before coming to rest, and these movements are apparent in the test data.

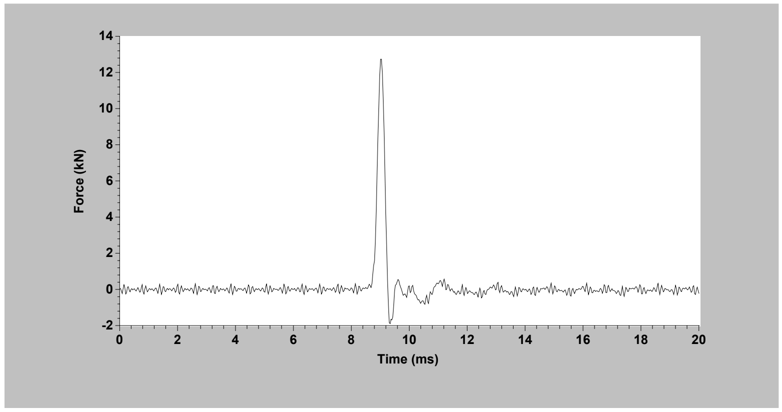

Figure 2 Impact forces experienced under a 3mm layer of Poron XRD (Peak force = 12.7 kN).

The materials tested were Poron XRD, D3O, GPhlex, EVA foam and a sample of unfinished leather. Poron XRD and D3O are market leaders for providing protection from impacts and are in widespread commercial use. GPhlex is a similar material but not yet in widespread commercial use. The EVA foam was derived from a Canterbury rugby shirt, and the leather was a sample of unfinished material obtained from cow skin. Samples of materials of different thicknesses were prepared with dimensions of 100 x 100 mm. Thicknesses were measured using a Shirley thickness tester.

Poron XRD is open cell urethane foam. When at rest above the glass transition temperature of the urethane molecules, it has softness and flexibility. When impacted quickly, the glass transition temperature of the material drops so that the urethane molecules stiffen to protect the wearer from damage.

D3O is comprised of a polymer composite which contains a chemically engineered dilatant, an energy absorber. This basic material has been adapted and enhanced to meet specific performance standards and applications. The material is soft and flexible in its normal state, however when impacted by force it locks itself and disperses energy and returns to its normal state.

Ethylene vinyl acetate (EVA) foams are described as a specific type of cross-linked closed cell polyethylene foam. They are designed to be soft, with a rubber-like texture and with good shape recovery after deformation.

Findings

Quantitative comparisons of a range of commercial materials used for impact protection have been obtained using the "Peak Force" parameter. The five materials selected for analysis are: Poron XRD, D3O, GPhlex, EVA Foam and unfinished leather. All have been subjected to 5J impacts using a 50 mm diameter steel ball. The mean peak forces are plotted against the thickness of the material in Figure 2.

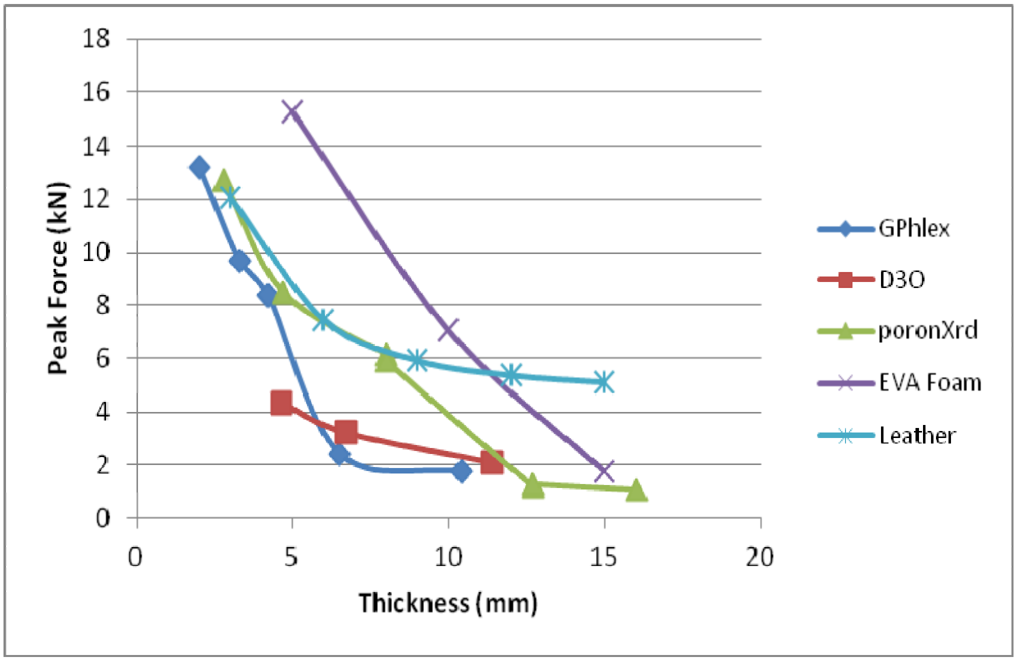

Figure 2 Peak force variations with material thickness

As a general point, where the peak forces were above about 10 kN, it was found that the materials were damaged in some way – usually identified by the presence of a hole. Peak forces lower than 10 kN sometimes left a surface mark, but more usually the material was elastically deformed and there was no visible sign of an impact.

Discussions

Four of the materials tested are commercial products designed to provide impact protection to the human body. The fifth is an untreated leather sample with a thickness of 3mm. This natural material is included among these materials for comparison purposes.

(a) Thickness effects

The reduction in peak force with thickness is entirely predictable, because all these materials absorb energy when impacted. Samples of 10mm thickness or more are effective in protecting against 5J impacts and the impacting sphere produces no surface damage. However, differences are apparent.

At 15 mm thickness, all the synthetic materials provide good protection at a level significantly better than 5 layers of the leather. The energy absorption capabilities of the synthetics appear to be comparable.

At 10 mm thickness, the EVA Foam is similar to an equivalent thickness of leather but the peak forces observed are about twice those obtained with Poron XRD, D3O and GPhlex. This suggests that EVA Foam has an internal structure that collapses more easily, reducing the performance of thinner samples.

With the 5mm thickness samples, there are three types of behaviour. D3O and GPhlex are the best performing materials. Poron XRD behaves much the same as leather, and the EVA Foam provides very little protection. 5mm thickness materials are important when considering the selection of materials for protective garments, particularly sportswear where the goal is not to restrict the athlete (wearers do not like thick and bulky inserts).

For 2 and 3mm thicknesses, those materials that have been tested do not show protection capabilities that are significantly better than leather.

(b) Garment design

If product designers are able to use 15 mm materials to provide protection, then their task is relatively easy, as the available materials all appear to be effective. Decisions about which material to use can be made on other grounds: cost, flexibility, comfort, ease of fabrication, etc.

The decision about which 10 mm thickness material to use has to recognise that the energy absorption properties vary considerably. It is not enough to know that a material is capable of absorbing energy – the issue is whether 10 mm provides the intended protection.

5mm thickness materials are important when considering the selection of materials for protective garments, particularly sportswear, where the goal is not to restrict the athlete (wearers do not like thick and bulky insert in their garments). Some products have been examined that suggest this issue is commercially important. Three leading rugby shirt brands offer products with impact protection, and all of them use an EVA Foam. In the shoulder region, the thickness is 10mm whereas the upper arms have 5mm thickness. Recent feedback from rugby players is that the shoulder protection is uncomfortable and restrictive. The laboratory tests suggest that the shoulder protection is less effective than it could be if other materials were used, and also that the 5mm upper arm protection is of little benefit to the wearer.

For 2 to 3mm thicknesses, product designers should realise that materials do not perform effectively and that the alternative of using a leather component of the garment may provide the same protection but have other advantages for the garment in use. This is an interesting area of research and we intend to look more closely at different types of leather and products that are engineered to have enhanced energy absorption at 3mm thickness.

Summary

Impact protection materials for sports wear clothing had been in gradual increase in sports such as rugby, cricket, hockey, etc, as sportsmen and women take intensive participation in sporting events. Critical review highlighted the range of materials available and the test standards, such as, industrial bump caps, BS EN 812:1997/A1:2001 and specification for head protectors for cricketers, BS 7928:1998 for measuring impact forces. Both these tests involved a striker falling on a surface, with the protective product experiencing the impacts. In this paper as the focus was on material properties, measurement of deceleration was of less interest. The force experienced by the transducer attached to the anvil which is under the protective material was measured. Five different materials were tested Poron XRD, D3O, GPhlex, EVA foam and a sample of unfinished leather. All have been subjected to 5J impacts using a 50 mm diameter steel ball. Figure 2 illustrated that peak force above 10 kN induced surface damage of the test samples.

Samples of 10mm thickness or more were effective in protecting against 5J impacts and the impacting sphere produced no surface damage. Bulky inserts and heavy protective pads restricted free movement of sports person; hence much focus was directed to product performance at 5mm samples. D3O and GPhlex were the best performing materials (5mm). Poron XRD behaved much the same as leather, and the EVA Foam provided very little protection. Leather with 3mm performed much better than the commercially available materials. This experimentation using the custom built equipment provided the basis for measuring the impact forces passing through the material. It also unearthed the possibilities of exploring a wide range of natural and synthetic materials for sportswear impact protection. Subsequent stages of research will consider design principles for materials that will perform better at low levels of thickness and explore various garment designs using different formats of materials for impact protection used for sportswear.

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