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Design of 3D Knitted Structures for Impact Absorption in Sportswear

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Abstract

Some sports involve frequent collisions between the players, and between a player and the playing surface, leading to injuries such as muscular strains, dislocations, sprains, lacerations, fractures and soft tissue injuries. In several instances, these injuries are so severe that they may cause bone fracture or dislocation of joints. In recent years, researchers are focusing on reducing these injuries by using protective gears and protective clothing to cover the torso, head, hands and legs. For rugby uniforms, shoulder pads are integrated to reduce the incidence of shoulder injury during the making or receiving of front-on tackles. Although some shoulder pads such as closed cell foams are commercially available, they are often discarded by the players due to their stiffness and discomfort. Hence, in this research an attempt was made to explore the potential of using flexible textile structures to replace the currently used commercial foam. Three flexible textile structures (A, B and C) were designed in three dimensional (3D) structure using Shima Seiki flatbed machine. Each fabric consisted of 3 layers, 2 external (face and back) and one internal layer. Fabric A consisted of mercerized cotton (space dyed) and Elastane external layers, whereas ballistic nylon internal layer. Fabrics B and C were prepared using Dyneema (untwisted) and Elastane external layers and Dyneema (untwisted) internal layer, but with different structures. These textile structures were analysed for their collision protection using the technique of 'drop test'. The test was based on principle of energy absorption by the textile structure due to the impact of a hard surface with them. It was assumed that the higher is the energy absorbed by the textile structure, the smaller will be the impact to the wearer. It was found that the 3D structures can provide equivalent amount of impact protection as the commercial foam (Sample D). The flexible structures recover easily with the body movement, and provide a high level of comfort. The methods of drop-test including the results are discussed in this paper. The findings of this study suggested that an equivalent level of protection can be achieved with the use of 3D textile structures and higher amount of comfort for the rugby players. Hence, the 3D textile structures can be used as an alternative material to replace the commercial closed foam currently in use in the shoulder pad to achieve similar protection and improved thermal comfort.

Keywords: Impact resistance, shoulder pads, knitted structure, thermal comfort, air permeability, thermal resistance, water vapour resistance

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1 Introduction

Rugby is a collision sport where injury is an inevitable aspect of the game [1, 2]. In a rugby match, repetitive impacts occur between the players as well as between the player and the playing surface. During a rugby match season, about 72% of the players experienced at least 1 injury per match, whereas about 82% of the players faced similar condition within a 1-year period. Majority of injuries in rugby or similar games have shown to be a result of not wearing appropriate impact protective clothing. Impact protective clothing usually contains cushioning materials integrated into specially designed areas of the apparels with the purpose of reducing the effects of sudden impact.

Although some impact protective clothing are readily available for rugby, they are often rejected due to restricted movement of body parts and/or very poor comfort properties of the clothing. In spite the athletes are aware of the benefits gained by wearing the impact protective clothing, they are reluctant to wear them due to the above reasons. One of the personal protections worn by the rugby players to reduce the impact from being tackled is padding. The most common form of padding is the shoulder pads, which were introduced to reduce the incidence of shoulder injury, during making or receiving front-on tackles. There are various styles and designs of shoulder pads commercially available. However, there have been few scientific studies which assess the protection capabilities of different shoulder pads including their comfort properties.

This research evaluated the performance properties of 3D knitted structures for impact resistance and comfort. The 3D knits were also selected due to their compressive behaviour and other relevant properties [3–5]. The 'drop test' was used to measure the effectiveness of the knitted structures in reducing the force of impact and dispersing applied forces away from point of direct impact. The concept of drop test was developed as an inexpensive quantitative method to compare and evaluate the impact protection of various fabrics. The comfort properties of the knitted fabrics were evaluated by air permeability, thermal resistance and water vapour resistance using standard test methods.

2 Methodology

2.1 Materials

Three different types of knitted fabrics (A to C in Table I) were manufactured and investigated. The results were compared with a commercial padding sample (closed cell foam, sample D in Table I) received from a rugby clothing manufacturer. The knitted structures were prepared from the blends of high performance fibres (such as ballistic nylon, and Dyneema®) and cotton yarns. The high performance fibres were selected

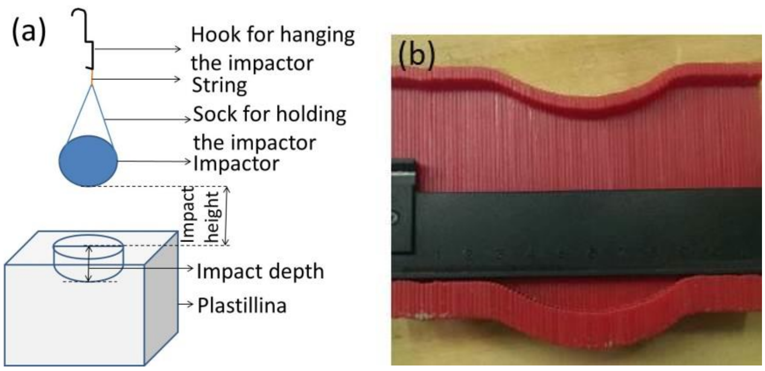


Figure 1: TEST SETUP USED FOR THE IMPACT TEST (A) AND PROFILER USED TO MEASURE THE INDENTATION LEFT ON THE PLASTILINA AFTER THE DROP TEST (B).

due to their exceptional high strength, whereas cotton yarns were used to provide improved comfort. Shima Seiki Whole Garment Machine (Model: SES-S-WG, 14 gauge) was used to manufacture the knitted fabrics. The microscopic images (20X) of the knitted fabric samples, as well the commercial foam used in this study are shown in Table I.

2.2 Methods

2.2.1 Evaluation of physical properties

Fabric thickness was measured by using the SDL thickness gauge (Model: IDU 25E) as per ISO 5084. Fabric areal density was measured as g/m^2 (GSM) following ASTM D3776-1990.

2.2.2 Impact test (Drop test)

The setup used to conduct the drop test is schematically shown in Figure I (a). The impactor used was a shot-put, which was placed inside a light-weight sock so that it did not add much weight to the impactor. The sock holding the shot-put was tied to a rigidly fixed hook with a string and adjusted at 4 different heights: 0.5 m, 1 m, 1.5 m and 2 m respectively from the test fabric placed over the plastilina. The impactor was dropped from these heights by cutting the string. The impact resistance was measured from the indentation left on the plastilina after the drop impact. The plastilina was conditioned at 37°C in an oven to simulate the skin temperature. The fabric specimens were conditioned in the standard atmosphere before the test. This test was conducted 3 times on each fabric and the average results for the depth of impact were recorded. A profiler (Figure I (b)) was used to measure the depth of impact created by the force of impact.

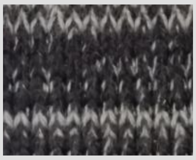
Fabric code	Layers 1/2/3	Fabric thickness (mm)	Areal density (g/m²)	Microscopic images (20X)
A	Cotton-Elastic yarn/ Ballistic Nylon/ Cotton-Elastic yarn	14.4	3477	
B	Dyneema (untwisted)-Elastane/ Dyneema (untwisted)/ Dyneema (untwisted)-Elastane	6.8	1586	
C	Dyneema (untwisted)-Elastane/ Dyneema (untwisted)/ Dyneema (untwisted)-Elastane	7.8	2194	
D	Commercial foam sample	15.3	582	

Table 1: Physical properties of 3D knitted fabrics and the foam.

2.2.3 Air Permeability, Thermal and water vapour resistance

Air permeability of the padding samples was measured using the SDL Atlas air permeability tester following ISO 9237 standard. The thermal resistance (R_{ct}) and water vapour resistance (R_{et}) or the breathability of the fabrics were evaluated in accordance with ISO 11092: 1993 under steady-state conditions using the Atlas sweating guarded hot plate (SGHP) as described elsewhere [6, 7].

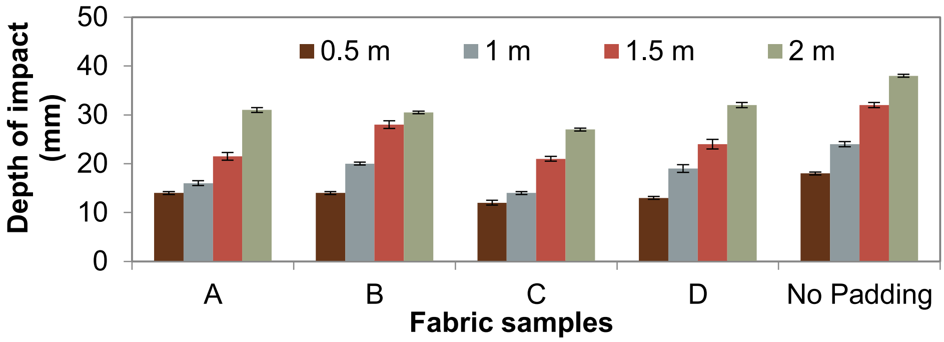


Figure 2: Depth of impact produced by the impactor.

Fabric samples	0.5 m	1 m	1.5 m	2 m
A	14	16	21.5	31
B	14	20	28	30.5
C	12	14	21	27
D	13	19	24	32

Table 2: DEPTH OF IMPACT (in mm) DURING THE DROP TEST.

3 Results and discussion

3.1 Impact test results

The depth of impact (Table II) was used as an indicator of performance of the shoulder paddings, which is graphically represented in Figure II. It can be seen that the 3D knitted fabrics (samples A-C) produced almost similar depth of impact compared to the commercial foam (sample D), in particular, for 2 m impact height, all 3D knitted fabrics performed better than the commercial foam. For all the impact heights, sample C produced lower depth of impact compared to the commercial foam sample D. The larger is the depth of impact, the higher will be the impact caused to the player, which will lead to more injury as the amount of deformation is linearly related to the impact energy.

It can be concluded from Figure II that the use of 3D knitted fabrics as well as the commercial foam in the shoulder pad helped in reducing the depth of impact to a certain degree compared to having no padding. Hence, the use of shoulder padding can provide impact protection to the rugby players.

3.2 Comfort properties

3.2.1 Air permeability, thermal resistance and water vapour resistance

The air permeability results of the fabric samples are graphically shown in Figure III (a). It can be observed from the figure that among the knitted fabrics tested in this

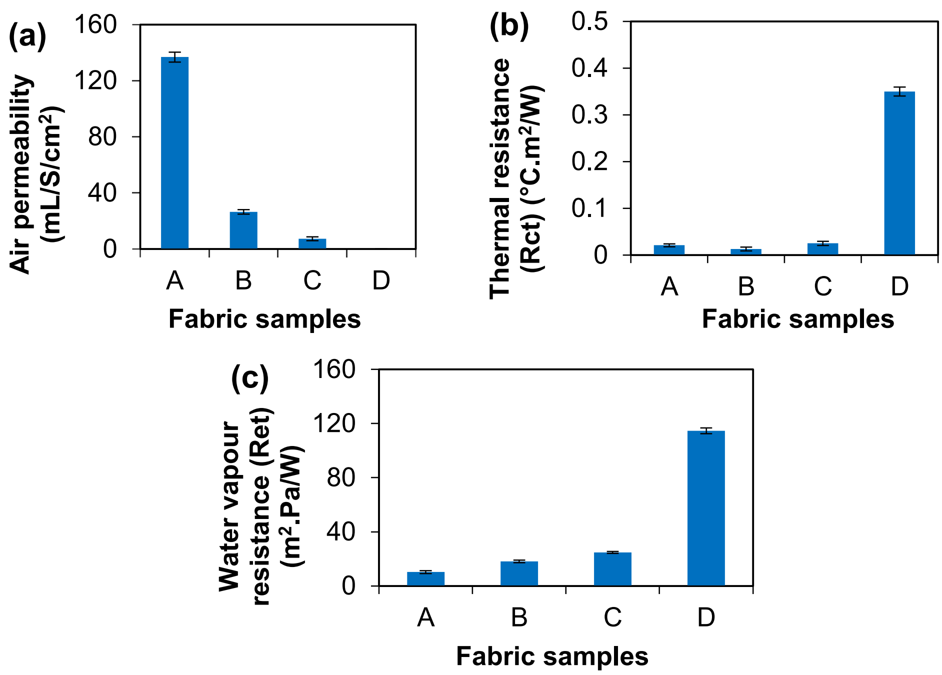


Figure 3: COMFORT PROPERTIES OF FABRIC SAMPLES: (A) AIR PERMEABILITY, (B) THERMAL RESISTANCE AND (C) WATER VAPOUR RESISTANCE.

research, the air permeability of fabric A is the highest, whereas it is the lowest for the fabric C. The fabric structure, fineness of the yarns in the fabric and the porosity of the fabrics affects the air permeability .[8]. It was observed that the foam shoulder padding used in the commercial rugby clothing showed close to zero air permeability. The zero air permeability of the commercial foam can be attributed to its nonporous close cell structure. The zero air permeability should be considered as a major concern with regards to comfort requirements desired by the players. The players wearing the clothing using the foam will not feel comfortable in the shoulder areas where the shoulder pad has been used. Hence, the high level of impact protection provided by the commercial shoulder pad is achieved by compromising the comfort properties.

The thermal resistance of the fabric samples is graphically shown in Figure III (b). It can be observed from the figure that the thermal resistance of the fabric C is the highest and that of fabric A is the lowest among the knitted fabrics investigated in this research. However, the thermal resistance of the commercial foam (D) is substantially higher than the knitted fabrics investigated in this research. Although, the commercial foam provided with a reasonable level of impact protection with the lowest weight, the wearer will feel much more thermal discomfort due to the heat stress by wearing the clothing consisting of the shoulder pads made of this foam. All the 3D knitted fabrics investigated in this research have much lower thermal resistance, which indicates that they can be potentially used for the shoulder pads to improve the thermal comfort, simultaneously achieving the desired level of impact protection.

The water vapour resistance of the fabric samples is graphically shown in Figure III (c). It is evident from the figure that the water vapour resistance value for the fabric C is the highest and fabric A is the lowest among the 3D knitted fabrics investigated in this research. The highest values of water vapour resistance for fabric C can be due to the lowest air permeability. The lowest R_{et} values of fabric C can be explained on similar basis to the air permeability. It can also be observed from the figure that the water vapour resistance of the commercial foam sample (D) is significantly higher than the 3D knitted fabric samples. The close cell foam structure of the fabric (as indicated by zero air permeability) prevented the flow of moisture vapour through the fabric structure. Regardless what level of impact protection, the comfort properties of the commercial foam are extremely poor. The knitted fabrics of this research have low water vapour resistance in the range of 10–25 m^2.Pa/W, which indicates these fabrics can provide satisfactory to moderate level of comfort. Hence, the shoulder pads of 3D knitted fabric can be used in design to improve the thermal comfort properties simultaneously achieve the desired level of impact protection.

4 Summary and Conclusion

It was established that the flexible 3D knitted textile structures can provide equivalent level of impact protection achieved by the commercial foam used in the rugby clothing. The flexible knitted structures can also provide higher level of comfort to the players compared to the commercial foam as indicated by higher air permeability and lower thermal resistance and water vapour resistance. Although the areal density of the 3D knitted fabrics was higher to achieve a similar level of protection compared with the commercial foam, the flexibility of the knitted structure will result in a lower level of dexterity problems. The close cell foam structure of the commercial foam can restrict the movement of body regions even in lower weight. The air permeability of the commercial foam padding was found to be close to zero indicating discomfort to the wearer. The wearer may feel high degree of discomfort in a physical game like rugby as there is absolutely no air movement to the parts covered by the shoulder pad. Furthermore, the thermal resistance and the water vapour resistance of the commercial foam were found to be substantially higher than the knitted fabrics investigated in this research. Hence, with the commercial foam padding, the player will feel high heat stress (due to high thermal resistance) and wet clinginess (due to high water vapour resistance) during the high level of sports activities, such as when tackling during a rugby game. On the other hand, the knitted fabrics used in this research can be successfully used to achieve similar level of impact protection provided by the commercial padding. In addition, the knitted fabrics will provide higher level of comfort to the rugby player during a game. The 3D knitted structures are suitable alternatives to commercial padding in garment design for impact absorption.

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