Advanced Measurement for Sports Surface System Behaviour

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Abstract

Artificial turf surface systems for sport can be comprised of a number of different materials. Measuring the surface system’s response to loading from player and ball is important for developing better understanding of its behaviour to enhance product design and optimise performance. Currently, simple mechanical tests are used to test and classify artificial turf systems for compliance to industry standards. However, little literature exists that describes artificial turf system response under player loading or the contribution of the components to the system response. This paper presents data for the stress-strain behaviour of the layer materials (one hockey turf and two types of shockpad) from laboratory controlled loading and data from a dynamic pressure measurement system. The results show strong non-linearity, hysteresis and viscoelasticity exhibited by the materials. The pressure measurement results show how the applied loads are dissipated within the system and demonstrate the differing response of two shockpads. The paper provides a contribution in understanding to the response of artificial turf systems to compression loading.

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Keywords: Artificial turf system; pressure distribution; material stress-strain behaviour; measurement systems

1. Introduction

Understanding the interaction between the player and the sports surface is an important area that has in general, received more research effort focussed on the player and their footwear and little regarding the surface behaviour. As the newer generations of artificial turfs have been developed, however, there has been more focus on biomechanical effects of interaction and optimising footwear stud configuration for example [1, 2]. Nonetheless, little published literature explains the effect of player (or ball) loading on the surface’s engineering behaviour or describes how the individual components of the surface system contribute to the system’s response. Whilst surfaces can be accredited for compliance with sport
governing body requirements, the (simple) mechanical tests are related to the system performance as a whole to compare to pass/fail criteria and do not readily permit the interpretation of engineering behaviour. The research programme presented in part here, aims to develop measurement systems and tools to understand real player/ball loading and their effects on the surface.

A typical artificial turf system can be split into two main sections, the foundation layer and the surface system. The foundation layer provides a flat stable platform, typically comprising a drainage system, an aggregate sub-base and in most cases a bound asphaltic top layer. The surface system usually comprises a shockpad layer and an artificial carpet layer (with or without infill) that together provide the required performance characteristics [3]. The behaviour of this system under dynamic loading is the focus of the research. The purpose of this paper is to outline the findings of a study measuring the surface system stress-strain behaviour under cyclic dynamic compression loading and pressure distribution from a thin mat transducer.

2. Test Method

An advanced Instron dynamic compression machine (ElectroPuls™ E3000, Norwood, MA, USA) was utilised to cycle load at different frequencies and measure the stress-strain behaviour of the artificial turf system. Figure 1 shows the typical test set up of an artificial turf system (25 cm × 25 cm) placed on top of a shockpad layer onto the Instron supporting platen. The mat transducer (Tekscan Inc.) was used to measure the real-time pressure distribution within the surface system layers. The samples used were selected from a recent associated PhD study on biomechanical loading.

![Fig. 1. Schematic of the measurement system design, showing the surface system of carpet and shockpad, the compression dynamic mechanical loading and pressure transducer placed within the surface system](image)

2.1. Samples and Loading Programme

A short-pile artificial turf used in hockey (no infill) and two shockpad products were selected, creating two different carpet-shockpad systems. The sample details (manufacturer’s data) are listed in Table 1.

The Instron machine was utilised to provide controlled cyclic loading (using the WaveMatrix™ software) to simulate walking (maximum load 978N and 0.9Hz) and running (maximum load 1840N and 3.3Hz) observed for an elite athlete (75 kg) [4] and also measure the displacement (at 1000Hz sample rate). Two sizes of loading foot, 50 mm and 125 mm diameters were used to simulate a heel and a forefoot [5], generating maximum contact stresses of 155kPa and 968kPa. Initial tests showed that a steady state for the cyclic loading (set as a simple sine wave) was quickly reached after 10 initial cycles so 40 cycles were applied. A small pre-load was applied (i.e. as a default zero load) to ensure continuous
contact during loading and unloading. Two combined surface systems were evaluated, comprising a hockey turf and two different shockpads.

Table 1. Specifications of the artificial carpet and shockpads used

| Sample      | Product name   | Thickness | Material and structure                                      | Manufacturer/supplier          | Density       |
|-------------|----------------|-----------|-------------------------------------------------------------|-------------------------------|---------------|
| Hockey turf | System 5       | 18 mm total| 12mm long nylon fibres, with a 6mm integral foam pad        | McCardle Astroturf            | N/A           |
| Shockpad A  | Regupol® 6010  | 15 mm polyurethane bonded rubber shreds | BSW Berleburger GmbH          | 550 kg/m³                   |
| Shockpad B  | re-bounce® uni | 12 mm polyurethane foam                | Recticel S.A.                 | 250±15 % kg/m³ |

2.2. Pressure measurement and analysis

The Tekscan Matscan transducer has a measuring range up to 862 kPa, a maximum scan speed of 500 Hz, is 0.18 mm thickness (with the protective cover removed for these tests) and a spatial resolution of 1.4 sensel per cm², a total of 2288 sensels across the mat, 44cm by 37cm. In accordance with the manufacturer’s recommendation and previous studies [6] the pressure mat was calibrated with a ‘Step’ calibration method comprising static loading. This calibration was then further validated using dynamic loading with the Instron machine by comparing the peak loads which were within 2%. The calibrated pressure mat was inserted between the hockey turf and shockpad and analysed using the F-Scan mobile research (v6.30) software to provide pressure-time maps and contact areas. The time base of the pressure mat recordings were synchronised to the Instron loading.

3. Results

3.1. Stress-strain behaviour

Figure 2 (a) shows the stress-strain relationships of the hockey carpet and the two carpet-shockpad systems under cyclic loading for different loading rates, for the larger test foot (area 123cm²). The results from the last loading cycle only are given. The stiffness response of the all the materials increased with increased loading rate, i.e. reduced compression strain. For the same loading rate and applied stress, the hockey turf with rubber shockpad (shockpad A) is stiffer than the hockey turf with foam shockpad (shockpad B).

Figure 2 (b) shows the stress-strain relationships of the hockey turf with the rubber shockpad system at two different loading rates and for the smaller test foot (area 19.6cm²). The greater load rate caused less strain in the system, similar to the findings from Figure 2 (a). The addition of a shockpad layer to the carpet increases the system elastic stiffness (i.e. reduces the observed strain albeit the layer thickness has increased) and the amount of increase is observed to be dependent on the shockpad type and the loading rate. However, the change of loading rate did not have a significant influence on the stress-strain behaviour of the rubber shockpad alone, specifically when the applied stress was lower than 600 kPa. From these data it appears the shockpad made from foam contribute to the system viscoelastic behaviour much more than for the shockpad made of rubber.
3.2. Pressure distribution results

The contact areas measured at the peak stress by the pressure mat between layers in are shown in Figure 3. The results show the applied loads were distributed over a larger area than the test foot by up to 49%. The hockey turf with foam shockpad system recorded slightly lower peak pressures than the hockey turf with rubber shockpad (87 kPa in comparison to 93 kPa). It is also interesting to observe that more high pressure points (indicated by warm colours) are displayed in the maps for the lower frequency loading, as shown in Figure 3 (b), (d) and that more high pressure points are displayed for the carpet-rubber shockpad system than the carpet-foam shockpad system for both loading rates. The reason for this is unclear at this time.

Fig. 3. Pressure distribution and contact areas measured between (a) hockey turf and foam shockpad layers at 3.3 Hz; (b) hockey turf and foam shockpad layers at 0.9 Hz; (c) hockey turf and rubber shockpad layers at 3.3 Hz; (d) hockey turf and rubber shockpad layers at 0.9 Hz
4. Discussion

4.1. Stiffness behaviour

To further analyse the stiffness behaviour, Figure 4 presents the stress-strain behaviour of the two shockpads from the final cycle of loading with the small test foot to a peak pressure of 500kPa. The lower density foam shockpad exhibits a much larger recoverable strain than the rubber shockpad for the same applied stresses. At increasing applied stress however the foam shockpad stiffness increases significantly and at a greater rate than the rubber shockpad.

A simple power-law model is useful to describe the non-linear stress-strain behaviour of the shockpads.

\[ \sigma = k \varepsilon^n \]  

Where the stiffness constant ‘k’ and non-linearity coefficient ‘n’ are depend on material properties and contact geometry [7]. If \( n = 1 \), the stress-strain relationship is a straight line. If \( n > 1 \), materials get stiffer when compressed and behave as non-linear, and the foam shockpad gives a greater non-linearity coefficient (4.8) than the rubber shockpad (2.57), but a lower k value for the linear part (n=1) of the curve. The non-linearity is attributed to the variation in both the materials and construction of the shockpads, specifically the closed form of the pore spaces in the foam relative to the open pore spaces in the rubber. The compression behaviour of rubber particulate shockpads has been observed in previous research to have three phases of compression relating to compression of: the voids; particles and voids; and the compressed particles at low void space [8]. The lower stiffness foam shockpad exhibits much larger strain than the rubber shockpad in the combined system. Whilst both these shockpads are used in the industry in surface systems it is clear that their behaviour is quite different and a player may perceive different under foot comfort (shock absorbency) during playing movements. However, it is also clear that predicting the strain produced under loading in a sport surface system is dependent on load area, rate of loading and the component material behaviour.

Fig. 4. The stress-strain response of the foam and rubber shockpads under cyclic loading (final cycle of 40)

4.2. Pressure distribution

The load applied on top of the surface system over a specific area is distributed over an increasing area as it penetrates through the layers, reducing the stress. The pressure mat is used here as a novel way of measuring the distribution and interaction between the system layers. The pressure-time map also
illustrates how the pressure develops and is distributed over the enlarged contact area. The pressure distribution is not wholly uniform however, possibly due to an inconsistency in the manufacture such as density (affecting stiffness).

The pressure measurements made using the thin mat system between the sport surface system layers is considered useful for further establishing the contribution of the layers to the system response to loading. However, some further work is required to ensure the mat does not have a reinforcing effect and alter the free-field strain response of the system. A real advantage of the pressure sensing transducer, in comparison to the traditional load measurements made on force plates, is to determine the pressure variation with time and the area of loading under controlled (mechanical) and uncontrolled (human) loading. By these methods the engineering requirements of the layers can be evaluated and hence designed for. In addition, in force plate testing it is often assumed that the force measured is that at the top of the upper surface layer (e.g. for inverse dynamic analysis) whereas using the mat transducer permits measurements of load and area. Further analysis of these test results during the period of loading and unloading are expected to yield more detailed insights into the viscoelastic behaviour.

Additional research is planned for integrating strain/deformation transducers to enhance the current test set up, and to incorporate more complex loading. By measuring the full stress-strain behaviour of the surface system response under in-game player loading, it is anticipated that future designs can be optimized and the data also utilized to validate numerical models of the surface system for behaviour prediction under more complex interaction scenarios.

5. Conclusions

Artificial turf systems and their component layers exhibit relatively complex stress-strain relationships through non-linear, viscoelastic and hysteretic behaviour. Controlled cyclic dynamic loading, with a pressure mat transducer, has demonstrated the pressure distribution provided by the shockpad layer under an artificial hockey carpet. This system analysis approach will permit greater understanding of real player loading and surface system response.

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