Title: The effect of maintenance on the performance of sand-filled synthetic turf surfaces

Short title: Maintenance of sand-filled synthetic turf

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Abstract

The effect of infill quantity and contamination on the performance of second generation sand-filled synthetic turf sports surfaces was investigated in a laboratory study. Three 1 m^2 test surfaces were constructed by placing synthetic turf over a stone – tar-macadam – rubber shockpad sub-base. Ball rebound, ball roll, surface rebound hardness and rotational resistance of a dimpled rubber sole were measured for a range of infill quantities (0-35 kg/m^2) and infill contamination concentrations (0, 10 and 20%). Increasing infill quantity increased hardness, reduced ball rebound and reduced rotational resistance linearly ($p < 0.01$). Ball deceleration increased up to 10 kg/m^2 after which there was no further significant increase in the range tested. An optimum infill quantity of 25-30 kg/m^2, based on performance characteristics and the length of fibre above the infill, was identified for the synthetic turf surface tested. Increasing contamination also increased ball deceleration and reduced infiltration rate and kept surfaces wetter for longer during drying ($p<0.001$), resulting in conditions suitable for moss and algae formation. Maintenance, including regular brushing and monitoring of infill quantity is required to ensure even distribution of the correct quantity of infill and the minimisation of infill contamination in all in-filled synthetic turf surfaces.

Keywords: Synthetic Turf, Maintenance, Performance, Infill, Ball roll, Traction

1 Introduction

Synthetic turf surfaces comprise tufted or knitted cut-pile carpets or woven or needle-punched (loop) carpets of synthetic fibres of various polymers (commonly polypropylene and polyethylene but historically polyamide) overlying a constructed base designed to provide a stable, level, free-draining, load supporting sub-base for the carpet. The majority of surfaces have a sand or rubber (or both) infill of the carpet to optimise mechanical behaviour for specified ball-surface and player-surface interactions. Further optimisation is achieved with sub-carpet 'shock-pads' – layers of elastic rubber beneath the carpet. The most common synthetic turf surface in the UK remains the 'Second Generation' (2G) sand-filled, short (ca. 25 mm) polypropylene fibre carpet, over a stone, tar-macadam, rubber shock-pad sub-base (Figure 1). 2G surfaces are a compromise surface for field hockey, bowls, football (soccer), tennis and multi-use games areas. A 'Third Generation' of longer-pile surfaces, in-filled with sand and rubber are becoming increasingly popular as they are more suited to football and rugby. There is increasing variation in surface design specification, with a range of fibre materials, fibre lengths, sub-base construction profiles, shock pads and infill materials as manufacturers and installers aim to reduce costs, increase durability and improve surface performance against international sports governing body criteria such as those of FIFA (2009), FIH (2008) and the IRB (2009).

Synthetic turf surfaces are more durable over a fixed time period than natural turf and can therefore increase the intensity of sport use per unit area. Maintenance requirements for synthetic turf are different from natural turf but synthetic turf surfaces should not be considered maintenance-free. Abraded particles from equipment such as footwear and hockey sticks, litter, air-borne contamination and soil and plant matter will accumulate in the surface and over time will be washed into the infill material reducing infiltration rate, causing the pitch to flood and creating the ideal environment for moss infestation (McLeod and James, 2007). McLeod and James (2008) reported a survey of 11, well maintained UK 2G sand-filled surfaces, used for 22 to 68 hours per week, in which a combined measure of these infill contamination types ranged from 2.1 to 9.1% by mass, increasing to 20% in problem areas (McLeod and James, 2007). They demonstrated in a laboratory study that infiltration rate of a 2G carpet reduced from 150 mm/h to 50 mm/h at 10% contamination of the infill. That study did not consider the effect of contamination on the playing performance of the surface, however. Maintenance aims to minimise contamination accumulation with frequent brushing using powered rotary brushes and drag brushes pulled behind a small tractor. Remedial techniques remove and clean or replace the infill (James and McLeod, 2008).

The depth of infill relative to the pile height is important. If infill depth is insufficient, there is not enough support for the fibre and the fibre will be subject to the phenomenon of capping (Figure 2), where the ends of the fibre fibrillate and fold over the infill permanently, reducing infiltration rate. An excess if infill will bury the fibre and play will effectively take place on fibre-reinforced sand. Play tends to redistribute sand through actions such as sliding, foot fall and stick strikes, resulting in a spatially uneven distribution of sand due to an uneven distribution of play and wear. This can be addressed by regular drag brushing. Routine topping-up of sand quantities is required because infill tends to be removed on clothing, equipment and machinery.

There are no published data on the relationships among infill quantity, infill contamination and pitch performance. We present a laboratory study that aimed to establish the relationship between infill depth, contamination and surface performance parameters (ball rebound, ball roll, traction and hardness) for sand filled, second generation synthetic turf surfaces. We test the hypothesis that there is an optimum infill quantity (for a specific fibre length) and that infill contamination is detrimental to surface performance, thus justifying maintenance of synthetic turf.

2 Materials and Methodology

2.1 Test surface construction and preparation

For surface hardness, traction, ball rebound and infiltration testing, three, 1 m x 1 m x 150 mm deep test surfaces, were constructed in steel trays. 100 mm of MOT Type 1X stone (graded on site at Cranfield University, UK) was compacted and overlaid with 25 mm of tar-macadam with 90% 6 mm crushed stone (Leisuretex Plus, Aggregate Industries, Coalville, UK). Over this was laid a 15 mm prefabricated SBR shock pad and a 24 mm pile height (BSW, Bad Berleburg, Germany), 44100 tufts/m^2, polypropylene synthetic turf carpet (Tiger Turf Multi Turf MP24, Tiger Turf UK Ltd, Hartlebury, UK).

A well sorted 0.71-0.25 mm diameter silica sand infill was used (2EW, Garside Sands, Leighton Buzzard, UK) at rates of 0, 10, 20, 25, 30 and 35 kg/m^2. Infill was applied in 5 kg steps and brushed into the surface with light compaction from a tamping device. For contamination testing, the sand infill was pre-mixed with a sandy loam soil (<0.5 mm) to simulate field contamination and then applied in the same way; infill was added at 25 kg/m^2. Grading curves for both these materials are shown in Figure 3.

For all ball roll testing, three longer (5 m) lengths of surface were laid on the level concrete laboratory floor and infill and contamination applied in the same manner. In this environment, vertical components of force are limited to gravitational effects and ball roll is a predominantly horizontal process and assuming that shock-pad stiffness is sufficient to resist deflection by the ball, the sub-carpet construction (sub-base) has a limited effect on ball roll and this adaptation is appropriate to facilitate measurement of ball deceleration over a 1 m distance without edge effects. Ball roll testing also investigated the effect of fibre-orientation. In these experiments, the synthetic turf surface was brushed using a polypropylene drag brush typically used in synthetic turf maintenance (Sweepfast, Sutton Coldfield, UK) with 150 mm long fibres of 2 mm diameter. For the napped surface (single fibre orientation) the surface was brushed 50 times in a single direction. The control treatment was brushed in four directions alternately for 50 cycles.

2.2 Determination of ball roll deceleration

A 160 g, 73 mm diameter, field hockey ball (Kookaburra, Corby, UK) was released from a height of 1 m (± 5 mm) down a 45° ramp conforming to EN 12234:2002. Two infra-red timing gates were placed to measure ball velocity over 100 mm at 2 m (v_1, m/s) and 3 m (v_2, m/s) from the base of the ramp. Mean ball deceleration (a, m/s^2) over 1 m (x, m) was determined using Equation 1.

$$a = \left(\frac{v_2^2 - v_1^2}{2x}\right) \tag{1}$$

2.3 Determination of ball rebound

The same hockey ball was dropped vertically without spin or impulse on to the test surface from 1.5 m as per the original FIH Handbook of Performance Requirements for synthetic turf surfaces, which required the ball to rebound between 100 and 300 mm for a surface of this type ('standard' approval level; FIH, 1999). Rebound height (± 20 mm) was measured from the surface to the underside of the ball using an array of infra-red gates mounted at 20 mm spacing on a guide tube (1.5 m x 110 mm internal diameter). Each gate comprised an infra-red emitting diode and matched phototransistor. A simple logic circuit was used to determine the furthest gate triggered twice after ball impact. This device has advantages over visual observation methods in that it can be operated by a single user or remove the time spent in video post-processing but is limited by the measurement resolution. A greater resolution can be achieved by a more closely spaced array. Since the development of the testing device, a second handbook has been published with an increased drop height of 2 m and a rebound criterion of between 100 and 400 mm ('national' approval level; FIH, 2008). Therefore, ball rebound data are normalised to drop height using the coefficient of restitution, as per Equation 2.

$$e = \sqrt{\frac{h_r}{h_i}} \tag{2}$$

Where, e is the coefficient of restitution, h_r is the ball rebound height (m) and h_i is the ball release height (m). The FIH (1999) criterion is $0.258 < e < 0.447$; the FIH (2008) criterion is $0.224 < e < 0.447$.

2.4 Determination of surface hardness

Surface rebound hardness was determined using a 0.5 kg Clegg Impact Hammer (CIH) dropped from 0.55 m height above the surface. The device comprises an accelerometer mounted in a 0.5 kg cylindrical aluminium missile (55 mm diameter) which is dropped down a guide tube (60 mm diameter) and the maximum deceleration on impact is recorded in the range of 0-444 ± 1.8 g (where g is multiples of the acceleration due to gravity). The CIH was dropped three times and the deceleration of the third drop was recorded. The initial potential energy for this device is 2.70 J. Dixon et al. (2008) observed that this is a 73% reduction compared to the 2.25 kg (0.45 m drop height) CIH normally used in human-surface interaction studies, however, it is similar to that of the hockey ball in the ball rebound apparatus (2.35 J).

2.5 Determination of rotational resistance

Rotational resistance, as a measure of shoe-surface traction, was determined using a torque wrench at the peak torque (± 1 Nm) when rotating from rest a disc with a dimpled rubber sole (150 mm diameter), loaded axially with 46 kg as per EN 15301-1:2007.

2.6 Statistical analysis

All methods were completed in triplicate for each replicate (3) of each test condition. Linear regression analysis was used to model performance behaviour where $p<0.05$. Analysis of Variance was used to separate treatment effects ($p<0.05$) and means compared using the Least Significant Difference ($p<0.05$). All statistical analysis was performed with GenStat v10 (Lawes Agricultural Trust, Harpenden, UK).

3 Results

3.1 Effect of infill quantity

The hardness of the surface increased linearly with increasing quantity of infill ($p<0.001$; Figure 4a). This is because as the quantity of infill increases, less fibre length is exposed (Figure 5) and less deformation of the fibre is possible, increasing deceleration on impact of the CIH. The hardness of the surface was inversely correlated with ball bounce ($r = -0.8966$; $p<0.01$), which decreased linearly with increasing infill quantity ($p<0.001$; Figure 4b). Lathrop et al. (2001) determined that the rebound height of a soccer ball decreased with increased infill quantity. They also observed that Clegg hammer impact was influenced more by shockpad than infill quantity but that was for a 2.25 kg missile, rather than the 0.5 kg used in this study. Studies of vertical cricket ball rebound on clay soil turf cricket pitches (Baker et al. 2001) and football (soccer-ball) rebound on sand-based natural turf (Spring and Baker 2006, Spring et al. 2007) have shown a positive correlation between hardness and ball rebound, although other authors (Adams et al. 2001) working on cricket ball bounce have reported no correlation between these parameters. Both the cricket and football surfaces studied are tightly bound by compaction and the grass plant and the stiffness of footballs and cricket balls is lower than hockey balls (Fuss, 2008; Ranga et al. 2009). In our study, closer inspection of ball bounce behaviour showed that there was horizontal radial redistribution of the unbound sand, reducing the energy returned to the ball on impact with the surface. Horizontal displacement was not observed on impact of the cylindrical Clegg Impact Hammer.

Increasing infill quantity decreased rotational resistance linearly in the range of 0-35 kg/m^2 applied ($r^2=0.853$, $p<0.05$; Figure 4c). At low infill quantities turf fibres and to an extent the infill were interlocked with the rotating dimpled rubber sole. At greater infill quantities, fibre – sole contact area was reduced and the infill had a low internal shearing resistance as rounded sand particles were able to mobilise with the shear stress of the traction device. Ball roll deceleration was non-linear ($p>0.05$ for linear regression). Analysis of variance determined that ball roll deceleration is best described by a linear increase in deceleration from 0-10 kg/m^2 followed by a plateau of non-significant change in deceleration between 10 and 35 kg/m^2 ($p<0.001$; Figure 4d). The initial increase in deceleration is due to the additional ball – surface friction caused by the additional infill material.

3.2 Effect of infill contamination

The effect of infill contamination was less marked than that of infill quantity. Contamination had an unexpected effect on hardness with a significant reduction at 20% contamination ($p<0.001$; Figure 6a). It was hypothesised that hardness would increase with contamination due to greater packing of the infill material due to contamination reducing the uniformity of grading of the infill and that this would cause an increase in coefficient of restitution. There is no significant effect of contamination on coefficient of restitution for ball rebound, however ($p>0.05$; Figure 6b). Likewise there is no significant effect on rotational resistance ($p>0.05$; Figure 6c) but there is a significant linear increase in ball deceleration with contamination ($r^2>0.999$; $p<0.01$; Figure 6d).

Infill contamination reduced infiltration rate significantly ($p<0.001$, Figure 7a). This is because the contamination reduces pore size within the infill matrix, reducing the conductivity of water into and through the infill. An effect of packing on reducing pore size is also observed ($p<0.001$; Figure 7a). Decreasing the pore size also increases water retention due to capillarity and consequently increasing infill contamination causes the surface to remain wetter for longer ($p<0.001$; Figure 7b). Reduced surface drying promotes an environment for moss and algae growth which can lead to slippery, unsightly surfaces with poor ball roll characteristics (McLeod and James, 2007) and it is hypothesised that the contamination provides a substrate for such biological growth.

3.3 Effect of brushing direction

Orienting fibres away from the ball roll apparatus reduced ball deceleration significantly compared to the upright fibres ($p<0.001$; Figure 8). When fibres were oriented towards the ball roll apparatus deceleration increased significantly compared to the upright fibre condition. When the ball is rolling against the fibre tips, there is greater resistance from the fibre and the ball is slowed and vice-versa. Brushing of the surface in one direction only would literally create a game of two halves, with a nap slowing the ball in one direction more than the other. It is essential to keep fibres vertical – a 'striped' surface achieved by creating an alternating nap would result in significant deviation of the ball in directions non-parallel to the nap.

4 Discussion

This study illustrates the importance of regular maintenance of synthetic turf surfaces. The quantity of infill has a significant effect on the playability of the surface. Determining optimum infill quantities is an optimisation of playability parameters and providing sufficient infill to support the turf fibre and prevent capping (Figure 2). To achieve the FIH:2008 criterion for ball rebound ($0.224 < e < 0.447$), infill quantity should be in the range 20-35 kg/m^2 (Figure 4b). In this range of infill quantity, the 95% confidence intervals for rotational resistance decreased from 32 to 15 Nm which is below the minimum threshold of FIFA (2009), although that particular standard is for studded footwear in longer grass in soccer.

Mean values of 0.33 for coefficient of restitution, 126 g for hardness (CIH 0.5kg) and 28 Nm for rotational resistance were reported in a survey of similar sand-filled surfaces (McLeod and James, 2008). Severn et al. (2007) reported a range of 25-33 Nm for rotational resistance of a similar test device on water-based synthetic field hockey surfaces.

There is no significant change in ball deceleration between 20 and 35 kg/m^2 (Figure 4d) but infill quantity in excess of 32 kg/m^2 would mean that the fibre would be buried under the infill (Figure 5) and less than 25 kg/m^2 would leave >5 mm of fibre above the infill, increasing the risk of capping. Therefore an optimum range of infill for this particular surface, compacted in this manner is 25-30 kg/m^2. Furthermore, the data highlight the importance of maintaining infill quantities which reduce over time and are spatially inconsistent due to wear patterns of different sports. Regular drag brushing to ensure even distribution of infill is important and topping-up of infill quantities may be required, but the direction of brushing must be rotated to prevent the formation of nap which can affect ball roll significantly (Figure 8).

The effect of infill contamination on playing performance parameters is less marked apart from for ball deceleration where there is a significant increase in ball deceleration with increasing infill contamination meaning that ball roll will be reduced significantly. This effect was observed on a dry surface. Increasing infill contamination reduces infiltration rate significantly. The FIH (2008) 'National' minimum infiltration rate is 150 mm/h. At 10% contamination the infiltration rate of the compacted infill (most similar to field condition) is below this criterion. Even in maintained surfaces, contamination can approach this number and is regularly exceeded where maintenance is not used (McLeod and James, 2008). Regular brushing of the surface with contra-rotating power brushes and prevention of contamination by maintaining clean footwear is essential to preventing degradation of infiltration rate. Synthetic turf facilities should be designed such that the ingress of contamination from footwear is minimised by providing clean pathways for both users and maintenance equipment to approach the surface, preventing contamination from surrounding soil and turf areas.

The laboratory analysis reported here was conducted on new synthetic turf with newly supplied infill over a relatively short period of time. The effect of exposure to the natural and playing environment is not considered in these experiments and they do not reflect a typical 15 year life cycle. Processes such as capping, infill contamination and moss growth occur over a longer time period than that tested here. Furthermore the effect of packing density has not been considered, except for infiltration rate testing and this should be explored further. The contamination added was soil, whilst representative of material brought in on footwear, it does not contain worn fragments of turf fibre or playing equipment which could affect the contamination experiments, but any differences are likely to be minimal. Of perhaps greater effect is the addition of contamination to the infill prior to application of the infill – thus distributing the contamination evenly through the infill profile. In the field, contamination accumulates at the surface of the infill profile and is then washed, brushed or driven into the infill from the top. Because the infill acts as a filter, this means that there is a gradient of contamination through the profile from the surface to the base of the carpet. This has a particular effect when comparing field contamination measurements to those in this laboratory study. The 10% of contamination measured in the field by McLeod and James (2008) was concentrated in the top of the profile, whereas it is evenly distributed in this study, such that contamination effects in the laboratory study are less severe than for the same concentration in the field. Once saturated, the infiltration of water into the infill is a function of infill pore matrix size and connectivity – a greater concentration of infill in the profile would reduce infiltration rate further than the data shown in Figure 7, which present a 'best case scenario'. So despite the limitations of the approach taken, the need for, and costs of, maintenance of synthetic turf remain justified and the mechanisms of surface performance breakdown remain the same.

Our study focuses on relatively short-pile (20-25 mm) sand filled surfaces. New installations tend to be longer pile (40-65 mm) and filled with both sand and rubber. The optimum infill quantities for 'third generation' surfaces of this type will be dependent on pile length and the purpose for which the surface is to be used due to varying force reduction requirements. However the need for ensuring even distribution of this optimum infill quantity/mix remains. There is an increased risk of infill contamination from abraded rubber infill and the infiltration and drainage mechanism is the same as the sand-filled system described above and therefore infill contamination must be minimised. In that sense the findings of this study are transferrable to the new generation of longer pile, sand and rubber filled synthetic turf surfaces.

5 Conclusion

The playability of a second generation sand-filled synthetic turf surface, in terms of ball rebound, ball roll and rotational resistance is significantly ($p<0.01$) affected by the quantity of infill, with an optimum 25-30 kg/m^2 of infill required for the 24 mm carpet tested. Adding contamination to the infill decreases infiltration rate and reduces ball roll speed significantly ($p<0.001$). There is no direct effect of contamination on rotational resistance or ball rebound ($p>0.05$). Having established the mechanism for surface performance degradation, the use and cost of maintenance that ensures even distribution of the correct infill quantity and minimises the accumulation of contamination, is therefore justified. An in-filled synthetic turf surface should not be considered as maintenance free and the minimisation of infill contamination should be considered from design stage through to operation.

Further work is required to determine the effect of both time and environment on the findings presented here, but they provide initial characterisation of the mechanisms of synthetic turf surface degradation.

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FIGURE LEGENDS

Figure 1 Typical construction profile for a ‘second-generation’ sand-filled synthetic turf surface shown to approximate scale.

Figure 2 Fibrillation and capping of fibres in a worn synthetic turf surface – typically caused by insufficient depth of infill.

Figure 3 Grading curves for the sand infill material and the soil ‘contamination’ used in the experiments.

Figure 4. The effect of infill quantity on surface performance: (a) hardness as determined by the 0.5 kg Clegg impact hammer (CIH); (b) coefficient of restitution for a standard hockey ball dropped from 1.5 m; rotational resistance of a dimpled rubber sole; (d) deceleration of a hockey ball over 1 m released from 1 m height down a 45° ramp. Values are means, with whiskers representing the standard error of the mean. Solid lines represent the linear regression model for the mean data where $p<0.05$; dashed lines are the 95% confidence intervals of the linear model, r^2 represents the coefficient of determination.

Figure 5. Mean length of fibre above infill depth for increasing infill quantity. Whiskers represent the standard error. The solid line represents the linear regression model of the mean data ($p<0.001$); dashed lines represent the 95% confidence intervals for the linear regression model.

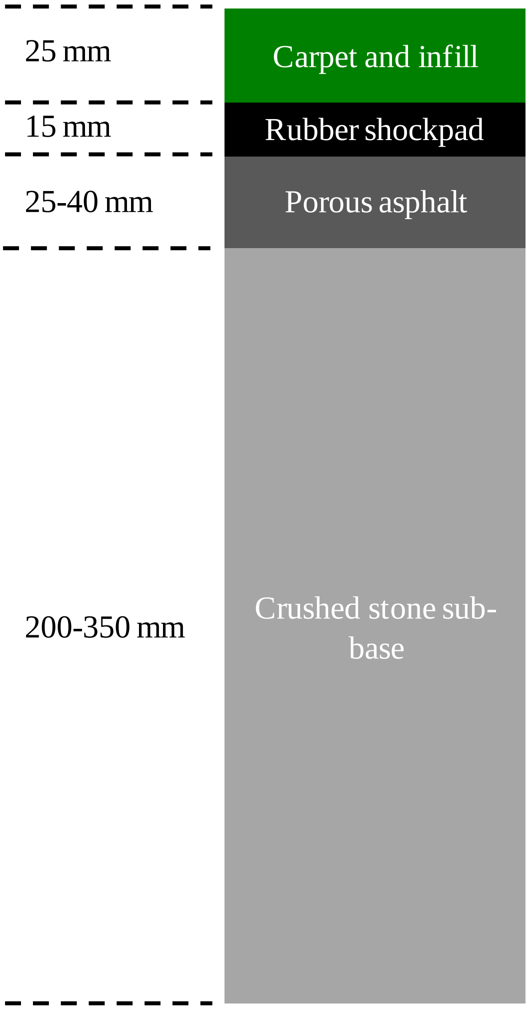
Figure 6. The effect of infill contamination on surface performance at 25 kg/m^2 of sand infill: (a) hardness as determined by the 0.5 kg Clegg impact hammer (CIH); (b) coefficient of restitution for a standard hockey ball dropped from 1.5 m; rotational resistance of a dimpled rubber sole; (d) deceleration of a hockey ball over 1 m released from 1 m height down a 45° ramp. Values are means, with whiskers representing the standard error of the mean. Solid lines represent the linear regression model for the mean data where $p<0.05$; dashed lines are the 95% confidence intervals of the linear model, r^2 represents the coefficient of determination.

Figure 7. The effect of infill contamination on (a) mean infiltration rate for loose and compacted infill and (b) surface drying (mean water content over time). Whiskers represent the standard error.

Figure 8. The effect of fibre direction on mean deceleration of a hockey ball over 1 m released from 1 m height down a 45° ramp. Whiskers represent the standard error.

TEXT FOR TOC

As the number of synthetic turf surfaces increases it is important that owners are aware that they are not maintenance free. This study looks at the effect of quantity and quality of infill, indicators of maintenance performance, on ball- and player-surface interaction.



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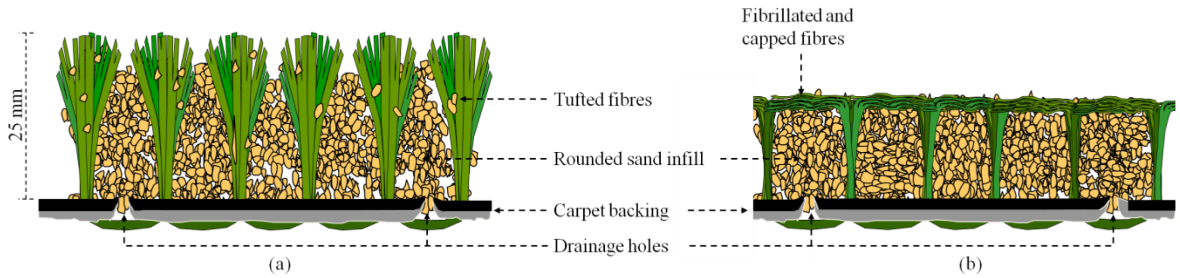

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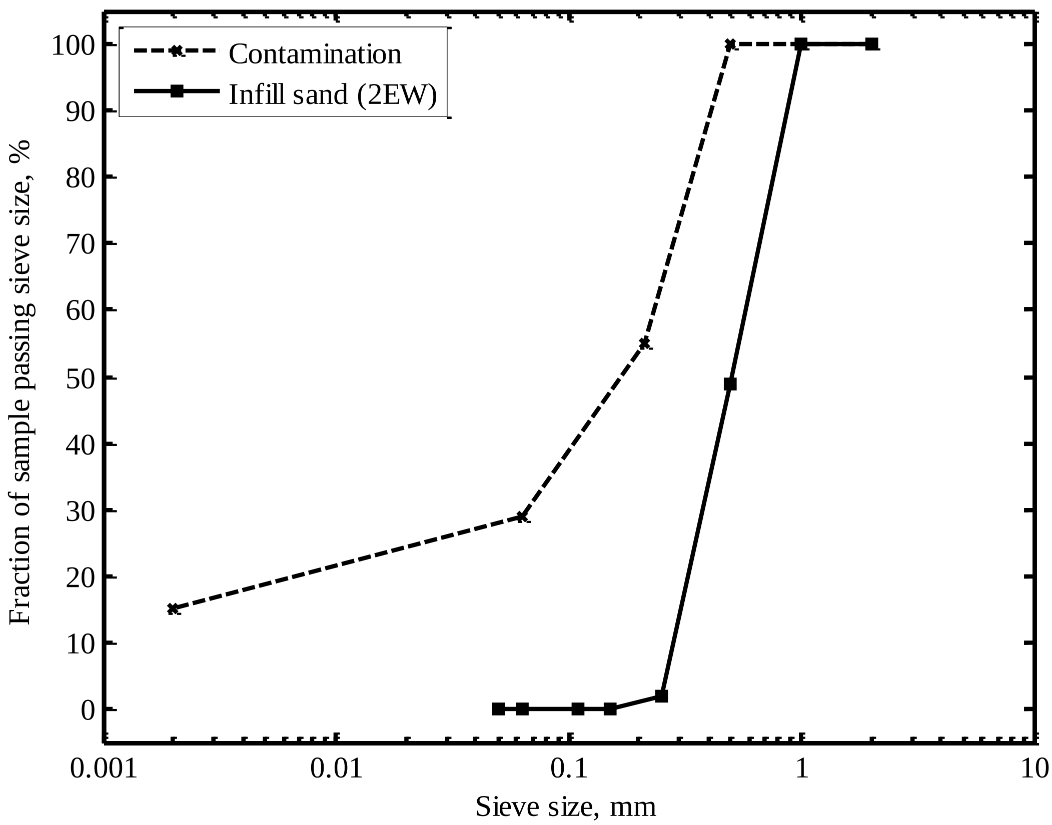
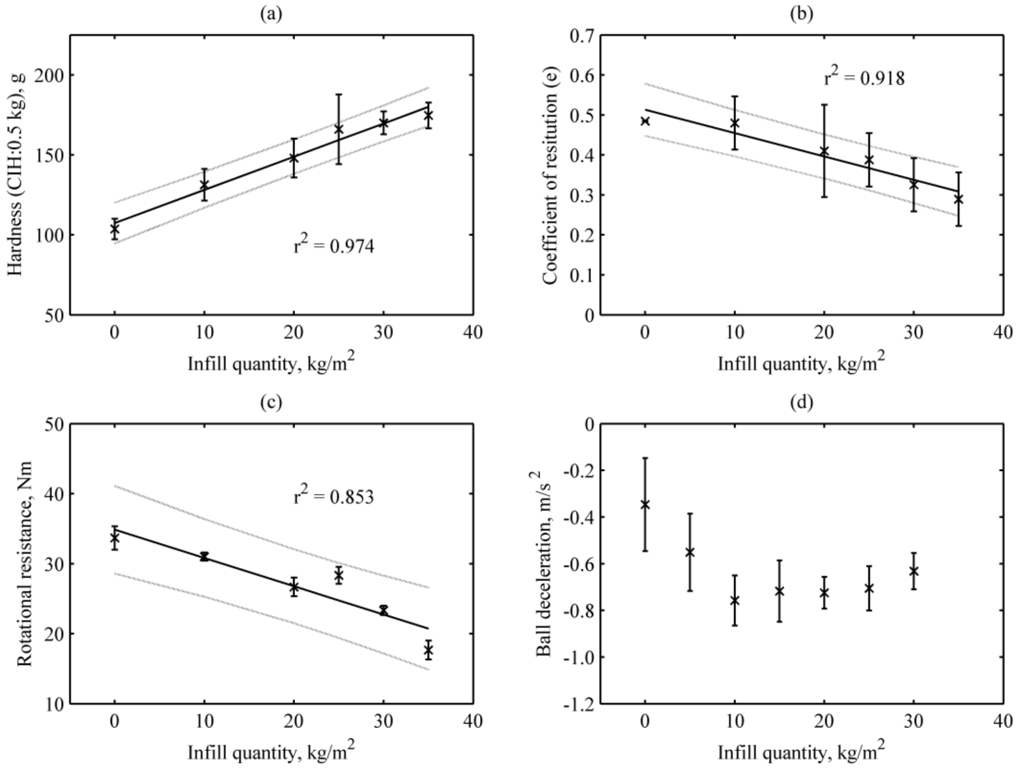


Figure 3 Grading curves for the sand infill material and the soil ‘contamination’ used in the experiments.

Figure 4



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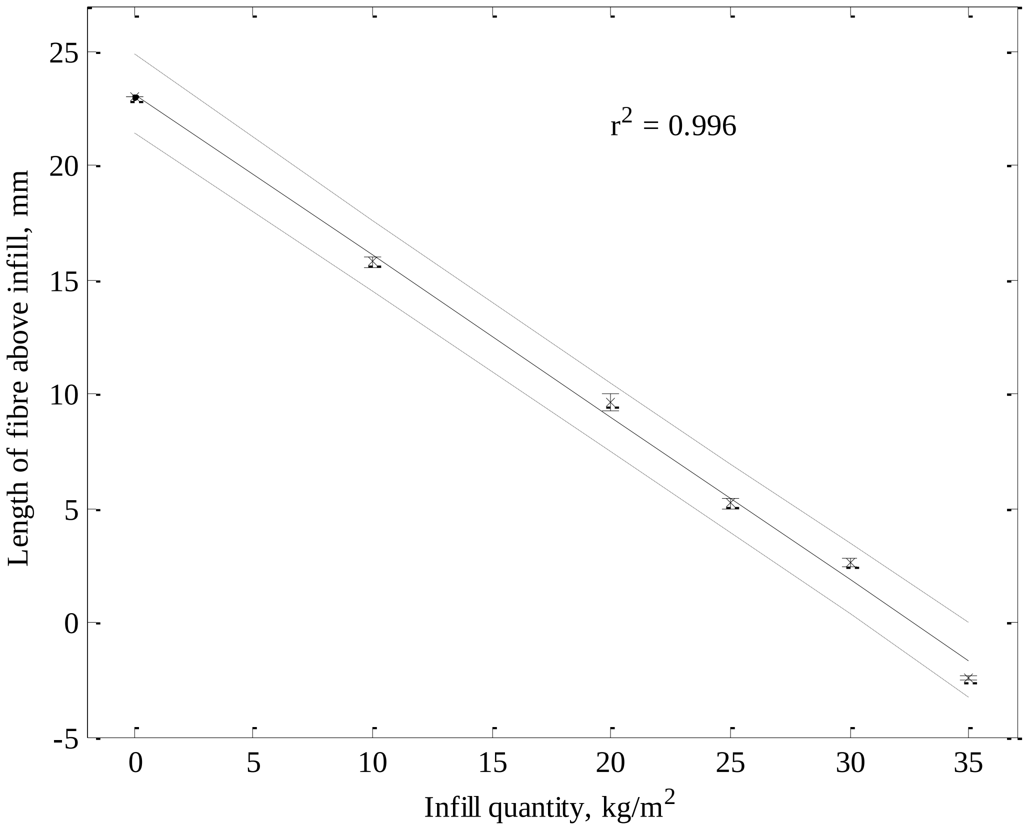

Figure 5. Mean length of fibre above infill depth for increasing infill quantity. Whiskers represent the standard error. The solid line represents the linear regression model of the mean data (p<0.001); dashed lines represent the 95% confidence intervals for the linear regression model.

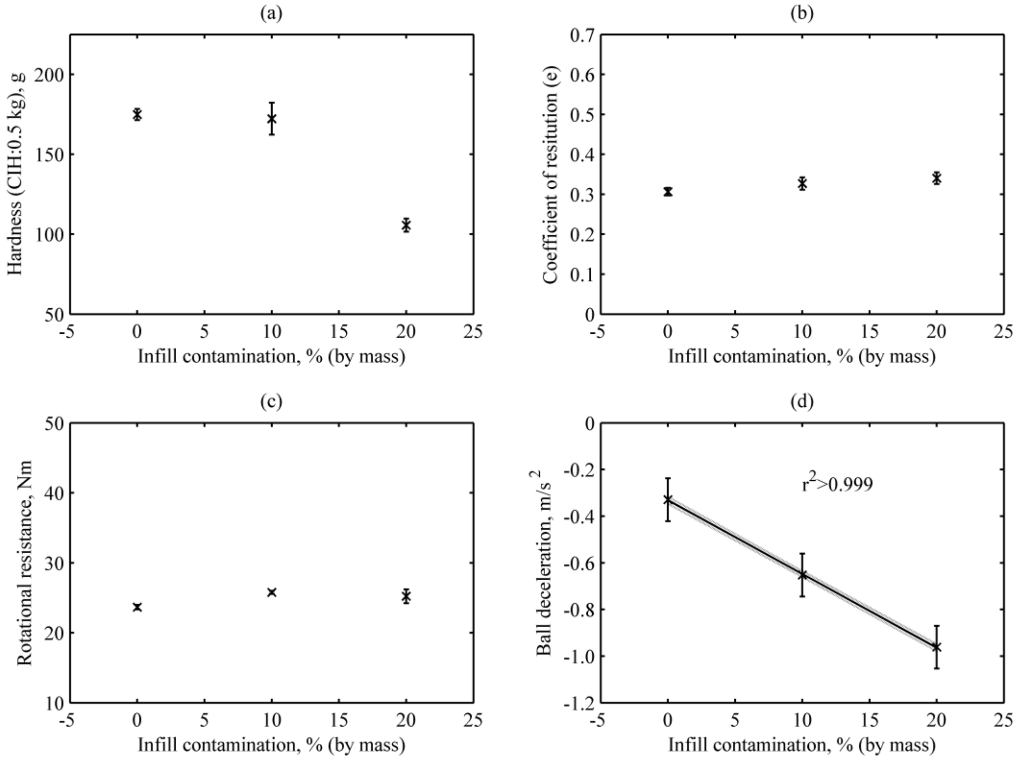

Figure 6. The effect of infill contamination on surface performance at 25 kg/m^2 of sand infill: (a) hardness as determined by the 0.5 kg Clegg impact hammer (CIH); (b) coefficient of restitution for a standard hockey ball dropped from 1.5 m; rotational resistance of a dimpled rubber sole; (d) deceleration of a hockey ball over 1 m released from 1 m height down a 45° ramp. Values are means, with whiskers representing the standard error of the mean. Solid lines represent the linear regression model for the mean data where $p<0.05$; dashed lines are the 95% confidence intervals of the linear model, r^2 represents the coefficient of determination.

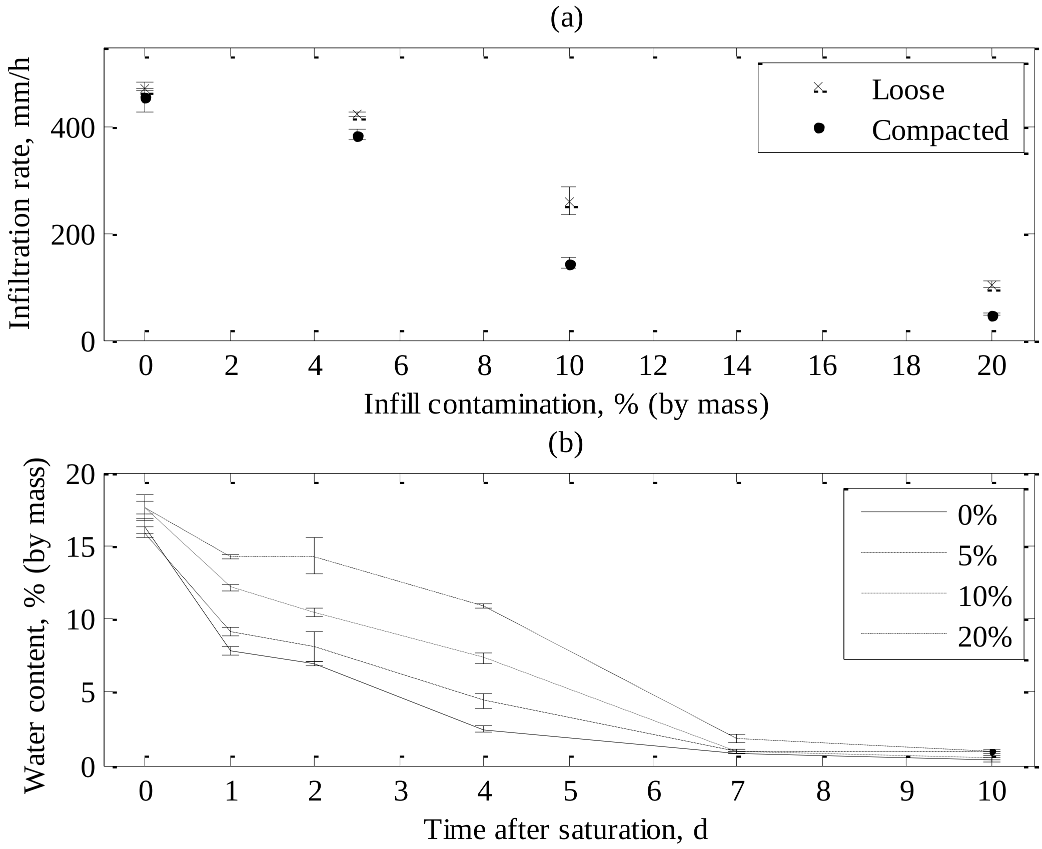

Figure 7. The effect of infill contamination on (a) mean infiltration rate for loose and compacted infill and (b) surface drying (mean water content over time). Whiskers represent the standard error.

Final draft of James and McLeod (2010). Sports Technology, 3(1): 43-51. DOI:10.1080/19346190.2010.504273

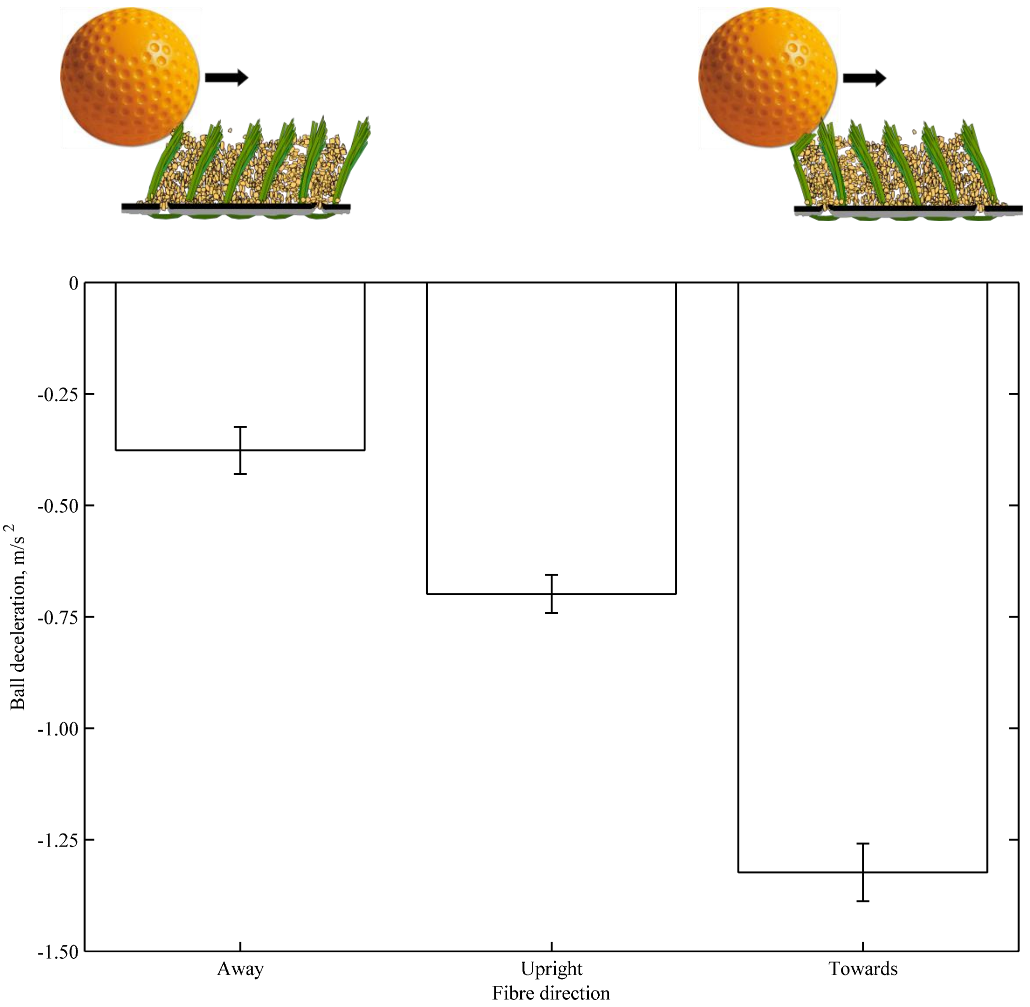

Figure 8. The effect of fibre direction on mean deceleration of a hockey ball over 1 m released from 1 m height down a 45° ramp. Whiskers represent the standard error.