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Rotational traction behaviour of artificial turf

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Abstract

Within artificial turf testing for player-surface interaction, traction is a key system property that needs to be measured for comfort, performance and injury risk. The purpose of this study was to modify a FIFA rotational traction test device to provide the full torque-angle time history and to use the modified device to compare the behaviour of five different football and rugby studs. A strain-gauge sensor and rotational sensor were incorporated to provide continuous measurement of the torque resistance and rotational angle throughout the rotation of the test disc. Data was collected on a standard laboratory made (3G) artificial turf surface. From the torque-angle plot, an initial high stiffness region followed by a lower stiffness region was identified and comparisons made between studs. In general, as stud length increased, the stiffness increased in both regions. Furthermore, as the stud length increased for both football and rugby studs there was a pattern of increasing peak torque but no clear trend for the peak angle. The actual foot rotation measured in subject testing is observed in general to be much smaller than the angular rotation required to produce the peak torque resistance from the mechanical testing, suggesting that the initial stiffness resistance behaviour may be a better indicator of the mechanisms involved in the traction mobilised by subjects.

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Keywords: Traction; artificial turf; torque; rotational stiffness

1. Introduction

Within artificial turf testing for player-surface interaction, traction is a key system property measured for comfort, performance and injury risk. Current industry tests used to measure traction (e.g. FIFA, IRB and RFL) are simplistic compared to the dynamics of the player-surface interaction and, as a result, a number of other test

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devices that aim to better emulate and/or quantify the boot-surface interaction have been developed (Kent et al., 2010; Kuhlman et al., 2010; Villwock et al., 2009).

The FIFA and IRB standards require a measure of rotational resistance using a specifically designed apparatus comprising of a metal disc with six equally spaced football studs on the base loaded to a mass of 46 kg. A calibrated torque wrench is used to record the peak torque generated by the surface from manually rotating the disc. The peak torque is required to lie within sport specific limits to demonstrate compliance (typically 25-50 Nm). One limitation of this approach for developing an understanding of surface behaviour is the single value of peak torque recorded with no further information on how the torque is mobilised with regard to rotation angle, with the peak often reached at around 40 degrees of rotation. Evidence of added instrumentation to the FIFA device has not been seen previously but a number of test devices have integrated instrumentation to output measurements throughout rotation of a disc or test foot which has allowed for further analysis (Kent et al., 2010; Livesay et al., 2006; Kuhlman et al., 2010). This is particularly relevant since it has been suggested that in reality the player's boot may rotate to a lesser extent than that at which the standard mechanical test achieves maximum torque (Kirk et al., 2007; Nigg et al., 2007, El Kati, 2012), and thus recording the rotational traction resistance may be more relevant to the player interaction. The purpose of this study was to use a modified FIFA rotational traction test device to compare the torque-angle behaviour for five different football and rugby studs.

2. Method

2.1. Equipment modification

Additional instrumentation was incorporated into the FIFA rotational traction test device to provide measurement of the torque and angle throughout the rotation of the test disc. A calibrated strain-gauge torque sensor was mounted below the existing torque wrench and a calibrated rotational sensor (potentiometer). The outputs of these sensors were sampled at 100 Hz and displayed in real-time using LabView, and saved for further analysis. The discrete value of peak torque from the manual torque gauge was still available following these modifications.

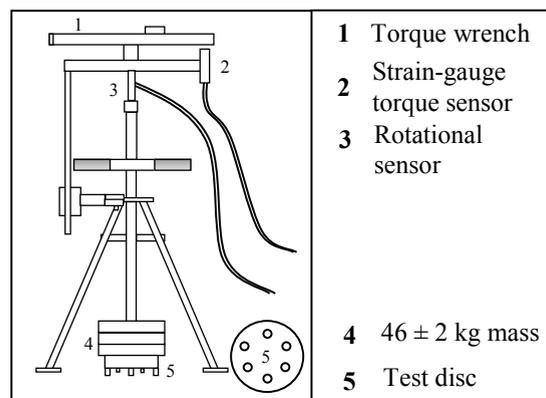


Fig 1. Schematic of the modified rotational traction device and studded plate.

2.2 Testing protocol

Testing was completed on a 3rd Generation football/rugby long-pile artificial turf sample measuring 1 m² - sourced from a recent new-build facility at Loughborough University. The 25 mm thick rubber shock pad, and the sand and rubber crumb infill were added (Figure 2a), following the same specification as the installed surface system. The surface was then conditioned by rolling 100 times with a standard roller (FIFA, 2012). Five test positions on the surface were selected (Figure 2b), and the surface re-conditioned by raking and re-rolling after a test had been completed at all five positions. The studs tested were: 13 mm and 16 mm football studs (FB); and 15

mm, 18 mm and 21 mm rugby studs (R), in the equally spaced formation of six studs (Table 1). Stud dimensions are shown in Table 1 and Figure 3.

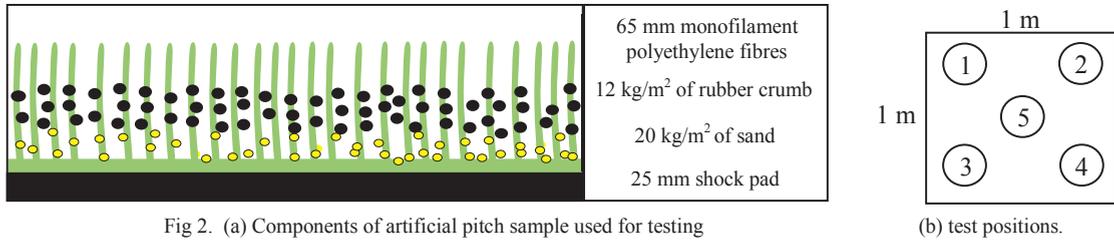


Fig 2. (a) Components of artificial pitch sample used for testing

(b) test positions.

Table 1. Stud dimensions (refer to Figure 3) and cross-sectional area for the five stud designs.

	Stud dimensions			Cross-sectional area of stud profile (mm ²)
	D ₁ (mm)	D ₂ (mm)	L (mm)	
13 mm FB	12	18	13	195
16 mm FB	12	18	16	240
15 mm R	6	20	15	195
18 mm R	9	20	18	261
21 mm R	7	20	21	283.5

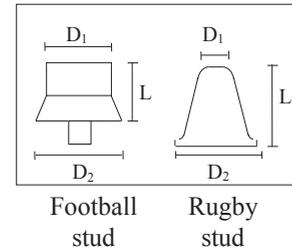


Fig 3. Stud section dimensions

The operator attempted to use a consistent speed of rotation between tests. Infill depth was measured using a depth gauge three times around each test position before each test to obtain an average infill depth. The average infill height across the five positions was 35.6 ± 0.6 mm. The room was kept at a constant temperature of 22°C.

2.3 Analysis

Time, torque and angle were output for each test from LabView to Microsoft Excel for further analysis and the peak torque from the torque wrench recorded. The time series were cropped from the start of movement to just beyond peak torque. The start of movement was defined as when the torque first exceeded 0.1 Nm. Peak torque is the maximum torque achieved in the test and the angle of peak torque was also recorded.

When torque was plotted against rotation angle (figure 4) the graphs typically illustrated an initial steep increase (A) followed by a longer more gradual increase (B). The gradient for region A was visually identified from the point where the plot began to increase steeply, until the first point where the gradient decreased. The gradient for region B was determined from the end of region A until a point just before the gradient begins to decrease, reaching peak torque. The change in torque was divided by the change in angle to determine the rotational stiffness (table 3).

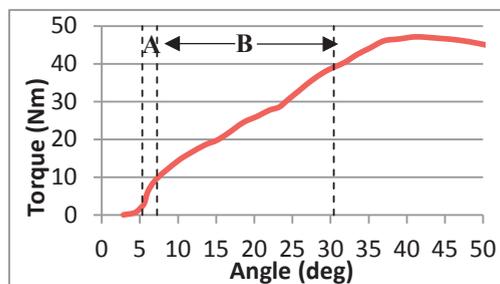


Fig. 4. Torque plotted against angle of the test disc for the 13 mm football studs at position 5 illustrating the steep increase in region A and the more gradual increase in region B.

A one-way analysis of variance (ANOVA) was performed using SPSS to assess the effect of stud design on the peak torque, angle reached for peak torque, and the two stiffness regions. When significant differences were found, a Tukey post-hoc test was performed to detect statistically significant differences between stud designs. Statistical significance was set at $p \leq 0.05$.

3. Results

A typical torque and angle against time profile is shown in Figure 5. The graph shows an initial build-up of resistance at the start of rotation, followed by an increasing torque as the test disc continues to rotate until peak torque is reached, after which the resistance reduces. Rotational velocity is consistent up until peak torque which occurs at around 40° of rotation. Table 2 presents the peak torque and angle data.

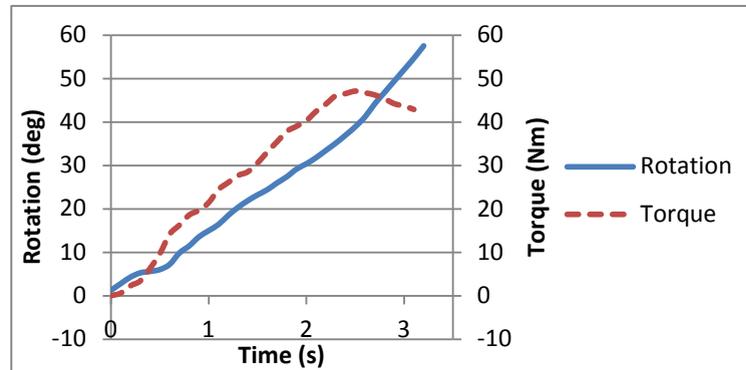


Fig. 5. Rotation and torque plotted against time for 13 mm football studs at position 5.

It was found that the peak torque produced by the 16 mm football studs was significantly larger than the 15 mm rugby studs peak torque ($p = 0.038$). However, there were trends showing that as the football stud length increased, peak torque increased and as rugby stud length increased, peak torque also increased. More data would be needed to identify further significant differences. The results in table 2 show that there is a good agreement between the strain gauge and torque wrench.

Table 2. Mean \pm SD peak torque and angle of peak torque for each stud design averaged over the five positions. Superscript numbers denote where statistically significant differences occurred between stud designs.

Stud type	Strain gauge Peak Torque (Nm)		Angle of Peak Torque (°)		Torque wrench peak torque (Nm)	
	Mean	SD	Mean	SD	Mean	SD
1 13 mm FB	47.2	2.8	43.6	4.1	46.8	3.9
2 16 mm FB	53.1 ³	4.1	43.8	4.1	52.2 ³	3.5
3 15 mm R	44.1 ²	4.1	39.1	5.8	42.8 ²	3.1
4 18 mm R	46.6	3.9	35.6	4.1	45.0	3.9
5 21 mm R	51.4	6.9	40.3	5.2	49.4	6.9
Mean \pm SD	48.5 \pm 3.7		40.5 \pm 3.4		47.2 \pm 3.7	

The rotational stiffness values for regions A and B are given in Table 3. The only significant differences found were between the 21 mm rugby studs and all other stud designs, except the 15 mm rugby studs in the initial rotational stiffness (region A), however there was a general trend that as the stud length increased, the rotational

stiffness increased. This is also observed in region B although there were no significant differences. The initial stiffness for the 21 mm rugby studs was significantly greater than that for the 13 mm football studs ($p = 0.008$), 16 mm football studs ($p = 0.046$) and 18 mm rugby studs ($p = 0.038$).

Table 3. Rotational stiffness values at the start of the movement (A) and further through the movement (B) for each stud design over all five test positions. Superscript numbers denote where statistically significant differences occur between stud lengths.

	Stud type	A		B
		Stiffness (Nm/deg)	Rotation (°)	Stiffness (Nm/deg)
1	13 mm FB	3.33 ± 0.46^5	2.43 ± 1.09	1.22 ± 0.13
2	16 mm FB	3.51 ± 0.30^5	2.10 ± 0.59	1.41 ± 0.22
3	15 mm R	3.85 ± 0.54	1.71 ± 0.24	1.29 ± 0.15
4	18 mm R	3.49 ± 0.28^5	2.81 ± 1.14	1.28 ± 0.19
5	21 mm R	$4.23 \pm 0.19^{1,2,4}$	1.86 ± 0.19	1.42 ± 0.16
	Mean \pm SD	3.68 ± 0.36	2.18 ± 0.44	1.32 ± 0.09

4. Discussion

The FIFA rotational traction test device was successfully modified with the addition of the strain gauge and rotational sensor which provided a full torque-angle time history (Figure 5). Five different football and rugby studs were compared for peak torque and angle of peak torque. Rotational stiffness was best represented by two values, an initial high stiffness and a second lower stiffness region.

A general trend was identified that as the football studs and rugby stud lengths increased, the peak torque increased. However the only significant different was between the 16 mm football studs and the 15 mm rugby studs. Clarke, 2011, found that as the stud length increased, no significant relationship with translational traction force was found. However, clearly stud geometry may be important as the cross-sectional areas in Table 1 show.

Villwock et al., 2009, completed a similar test with a mechanical test device using real boots and looked at the rotational stiffness between the start of the test until 75% of the peak torque. The mean stiffness values found using an artificial surface most comparable to the one in this study, were 3.1 Nm/deg and 3.4 Nm/deg, with two different models of 7-studded football boots. This is within 10 and 15% to the mean value in this study where stiffness is first developed of 3.7 Nm/deg (table 3). Livesay et al., 2006, used a similar test device to the modified test device in this study using the forefoot of a grass and turf shoe to complete some preliminary testing and found two stiffness regions, which this study agrees with. The first region was characterised by an initial steep increase in torque with applied rotation of the shoe (between 0 and 2°), with the second region being where there was a linear increase in torque with additional rotation (between 2 and 10°) before peak torque was reached. Livesay et al., 2006 also found in their testing that peak torque and rotational stiffness scaled linearly with compressive load by performing five trials at five different compressive loads, to 511 N, comparable to the load used in this study. A comparison can be made to Livesay et al., 2006, between the two regions for rotational stiffness, looking at results from 12.7 mm cleated boots. Comparing the initial stiffness in region A, the stiffness found in Livesay et al., 2006, was 3.1 Nm/deg compared to 3.69 Nm/deg here. The second linear region (between 2 and 10° for Livesay et al., 2006) corresponds to region B in this study, was approximately 1.0 Nm/deg compared to 1.32 Nm/deg here. It is worth noting the surface used (polyethylene fibres, 100% rubber infill) was not identical to the one used in this study, which may affect the results.

El Kati, 2012 used human subjects to perform sport specific movements including a stop and turn manoeuvre. During the stop and turn movement, it was found that rotation of the foot was, in fact quite small. On average, the foot rotated a total of 11.6°. When comparing this value to figure 5, peak torque would not be reached suggesting the early behaviour may be a better indication of the relevant player-surface contact mechanisms involved. This highlights the importance of completing human testing alongside mechanical testing to ensure the appropriate data

is being interpreted. The notable difference between subject testing and the testing completed in this study are the differences in vertical impact force. El Kati, 2012 found a peak vertical impact force of almost 2 body weights.

To explain the behaviour observed it is hypothesised that as the studded test disc (fully loaded to 46 kg) is dropped from the specified height of 60 mm, initial stud penetration and vertical compression of the infill may provide a zone of stiffer infill around each stud. Early movement shows this higher resistance at region A. The fibres provide reinforcement which contributes to the high resistance. Once the stud disc reaches approximately 10°, the studs are 'through' this stiffer zone and into a more consistent infill and fibre mix (region B). The resistance builds up as the infill is compressed and the fibres resist infill displacement or shearing. The peak torque is reached just before the infill/fibre zone in front of the stud fails, due to shear and/or the stud reaching a point close to the path of the preceding stud.

The amount of vertical stud penetration into the infill was not measured, however should be considered in future testing. It would also be more realistic to test with a higher impact force to better replicate a human movement, for example closer to 150 kg, or the equivalent of 2 body weights. This may cause further penetration of the studs or compression of the rubber crumb, thus increasing the infill density and its stiffness and resistance to shearing (Severn, 2010). Future testing will enable a football or rugby boot to be attached to the device, instead of a smooth studded disc. A variety of surface systems will also be used in future testing.

5. Conclusion

This study has shown the development of the rotational traction apparatus, with additional strain-gauge and rotational sensor and shown that traction appears to be mobilised at different rates regarding the angle of rotation. The additional instrumentation provides a better indicator of the mechanisms involved with the modification and method for measuring traction having potential to be used in the future for football and rugby. This permits further hypothesising as to how traction may be mobilised under human movement and loading. The stiffness behaviour at two stages of the rotation was observed; an initial high stiffness followed by a lower stiffness region. The general trend found was that as the stud length increased, the initial stiffness increased with the exception of the 15 mm rugby stud for peak torque and angle of peak torque. A significant difference was found between 16 mm football studs and 15 mm rugby studs, however there were no significant differences between the other stud lengths. As the stud length increased for both football and rugby studs there was a pattern of increasing peak torque. When compared to foot rotation produced in a subject testing trial, it was clear that peak torque would not be reached. It is suggested that the early stiffness behaviour may be a better indicator of the mechanisms involved in player-surface traction.

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