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ScienceDirect

Procedia Engineering 72 (2014) 877 – 882

Procedia Engineering

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The 2014 conference of the International Sports Engineering Association

# Effect of varying the volume infill sand on synthetic clay surfaces in terms of the shoe-surface friction

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## Abstract

The friction developed by the shoe-surface interface on artificial clay has not been widely studied, and can influence player's performance and injury risk. The aim of this research was to investigate the effect of varying the quantity of infill sand on shoe-surface friction on an artificial clay court tennis surface. A laboratory-based mechanical test rig was used to measure the friction force developed at the shoe-surface interface. Additionally, the perception of a group of participants, performing a turning movement on the same surface under dry conditions, was collected in order to compare against the mechanical results. The relationship between the normal force and friction generated by the shoe-surface interaction was examined for surfaces with different sand in-fill volumes. The mechanical testing was performed under dry and wet conditions, showing strong and significant differences. Results indicated that the normal force significantly influenced the static and dynamic frictional forces. For lower sand infill volumes, as normal loading increased, the dry condition was found to exhibit the lowest peak static friction force and highest average dynamic friction force. However, for higher sand infill volume conditions, the opposite behaviour was observed. Strong and significant positive linear relationships were found between peak friction force and average dynamic friction force for all infill sand volumes and conditions. The mechanical results were in agreement with the perception data, which suggests that the participants were sensitive to the small changes in sand infill volumes.

The findings of this study will therefore aid the understanding of tennis players' perceived response to a tennis court surface. In order to get a better understanding of friction behaviour, further testing needs to be performed, and once the mechanisms involved are understood, surface properties could be modified to increase performance and reduce injury risk.

Keywords: Tennis; artificial clay; infill sand; friction

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doi:10.1016/j.proeng.2014.06.149

## 1. Introduction

Tennis is a sport characterised for being played on a variety of court surfaces. The professional tournaments are played on grass, clay and acrylic hard court surfaces. Dixon et al. (1999) suggested that the frictional characteristics of the playing surface affect the risk of accidental injury occurrence. On clay, there is no regulation on the optimal clay parameters (e.g. particle size) used for the preparation of a clay court. In consequence, the variety of clay courts around the world influences, in different ways, the frictional properties of a shoe-surface combination, and hence players' performance and injury risk. Due to the nature of the clay surface, players are more likely to perform lateral controlled sliding movements to reach the ball. Therefore, the shoe-surface interaction on clay courts must be studied, with the objective of determining an optimal range of clay volume to reduce the injury risk and secure the performance of the player. Artificial clay courts have become widely popular around the globe, due to their lower maintenance cost and the ability to simulate clay court conditions. Artificial clay courts are defined as a dense, polypropylene carpet surface, designed to be over filled with sand, replicating a clay court. From a research perspective, artificial clay similarities with clay courts could help understand the frictional mechanisms involved during a shoe-surface interaction. Previous studies have investigated the tribological mechanisms of different artificial clay court tennis surfaces (Clarke et al. 2013), via a laboratory-based mechanical test rig. A relationship was found between the particle size of an artificial clay court and the friction generated by the shoe in contact with the surface. It was established, under a range of vertical forces, that small dry particles develop greater friction compared to increased particle size, which generally reduces friction. However, no previous authors have attempted to study the effect of volume infill sand on artificial clay tennis surfaces and the player perception to these changes.

Therefore, the aim of this research is to investigate the effect on shoe-surface friction of a sand-based artificial clay court tennis surface, by varying the quantity of infill sand, and then attempt to validate the results through measurements of player perception.

**Nomenclature**

| | |
|---|---|
| ACC | artificial clay court |
| GRF | ground reaction force |
| Qual1 | quality of movement 1 |
| Qual2 | quality of movement 2 |

## 2. Method

The laboratory-based traction testing device, shown in Figure 1a, was used for testing the commercially available ACC. The operating procedures of the rig are described by Clarke et al. (2013). The acrylic clay court surface tested is the one used in the studies by Damm et al. (2011) and Clarke et al. (2013). It was tested under different volumes of infill sand in dry and wet conditions (Table 1).

Table 1. Artificial clay court description and volumes tested

| Surface reference name | Description | Quantity of sand infill |
|---|---|---|
| ACC (Artificial Clay Court) | A polypropylene fibrillated membrane (carpet) with sand infill. Manufacture specifications are: pile weight is 700 g/m$^2$ and pile height is 11 mm. The quantity of sand infill recommended is 12 kg/m$^2$. Particle size > .060 mm. Total height is 13 mm. | 10 kg/m$^2$<br>12 kg/m$^2$<br>16 kg/m$^2$<br>20 kg/m$^2$ |

The test procedure was designed to best replicate a sliding movement. According to Damm et al. (2011), the peak vertical GRF of a tennis player will exceed 1000 N during specific movements like side jumping and sliding; therefore, the friction tests were conducted under a range of normal forces. First, the forefoot section of a clay shoe sample is attached onto a shoe plate with a preloaded contact angle between the outsole and the surface set at 7° (Figure 1c). The synthetic clay surface is then secured on a platform that is slid into place via a bearing and rail system before being secured. Before testing, the outsole was cleaned with an ethanol solution and allowed to dry at ambient temperature. Prior to testing under each condition, the outsole was prepared by applying p400 silicon carbide paper by hand under minimal pressure. Any debris from the shoe was removed using a clean, soft, dry brush. These procedures are in accordance with parts of BS EN ISO 13287:2007 (International Standard: Personal protective equipment. Footwear. Test method for slip resistance). The front shoe attached was rotated 90° to the direction of the movement in order to replicate the likely shoe orientation during a sliding movement. The shoe plate and assembly move horizontally on low-friction roller bearings, and the maximum sliding length is 250 mm.The artificial clay surface was rigidly attached within a Perspex tray in order to contain the particles of sand. The sand was brushed by hand into the membrane, and then further particles were added in order to meet the specifications as shown in Figure 1b. Prior to every test run, the particles were brushed to ensure an approximately even distribution of particles over the membrane. For wet conditions, the quantity of water used was the same described by Clarke et al. (2013) which aimed to simulate 24 minutes of play in light rainfall (1 mm of rainfall in total. Water was added with a calibrated sprayer. The water was sprayed by hand, being careful to cover the surface evenly.

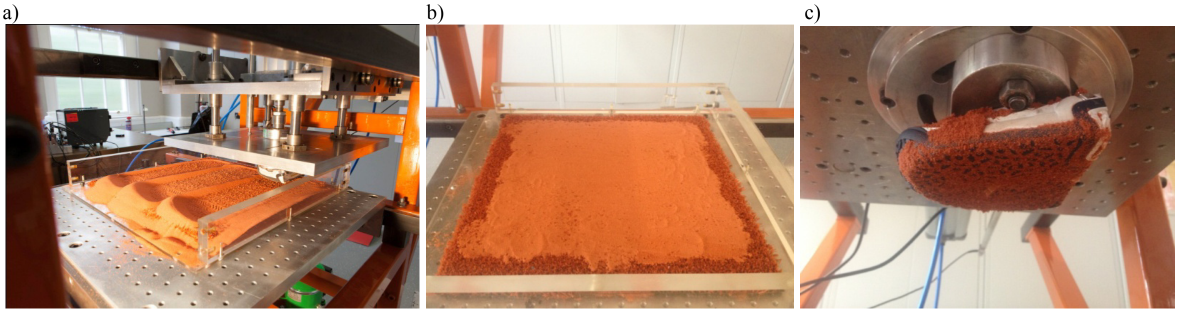

Fig 1. (a) The laboratory based traction rig UoS1; b) Synthetic clay surface prepared and mounted; (c) Shoe sample attached

Perception data were collected at the University of Exeter. A group of 16 participants volunteered to participate in the present study. Perceptions were collected using visual analogue scales following the trials on each surface. The scales were 100mm length, being 0 and 100 low and high perception from the player for each parameter. The perception parameters evaluated by the participants were: (1) predictability, (2) grip, (3) hardness, (4) Qual 1, (ability to change direction), and (5) Qual 2, (ability to slide). The participants performed a turning movement (180° turn at 3.9 m/s ± 0.20 m/s) on three different volumes of sand 12 kg/m$^2$, 16 kg/m$^2$ and 20 kg/m$^2$ respectively (Figure 2). Mixed model ANOVA was used to examine the influence of the group and volume of sand perceptions (significance = $p < 0.05$). Additionally Pearson's $R$ correlations were conducted to examine associations between quantity of sand and perception data.

Fig. 2. Example of participant performing a turning movement on the artificial clay surface

## 3. Results

A full description of the methodology used to obtain the parameters from the experiment is explained in the study by Clarke et al. (2013). From typical plots of horizontal friction force against displacement, peak friction force and the mean dynamic friction were calculated for each infill sand condition (Figure 3a).

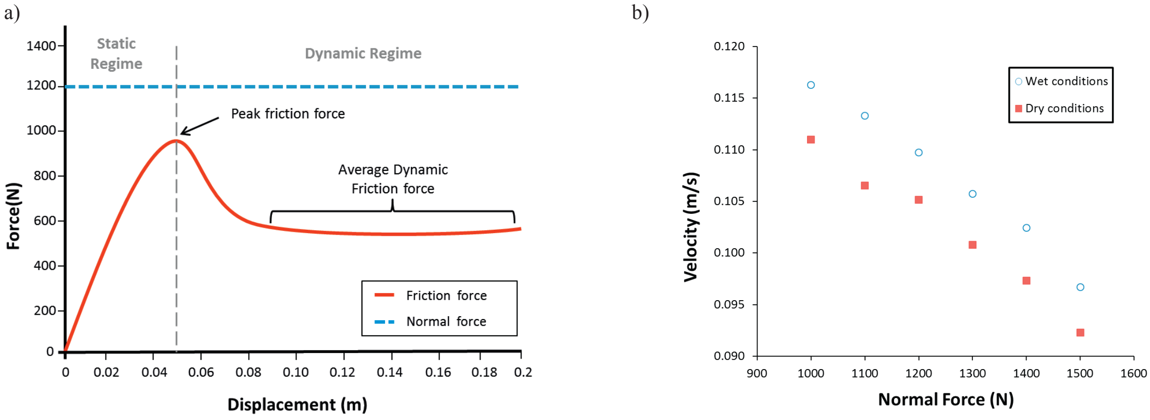

Fig. 3. Static and dynamic regimes for a typical test, showing the values of peak and average dynamic friction force.

Linear regression analysis was used to analyse the relationships found for the different conditions. The square of the Pearson correlation coefficient ($R^2$) was used to determine the strength of the linear correlation between the data sets. The corresponding p-value was used to determine whether the linear relationship was statistically significant. If $p < 0.05$, then a significant relationship between the two data sets is said to exist. Table 2 shows strong and significant linear relationships found for each surface condition tested against the normal force applied ($p < 0.05$).

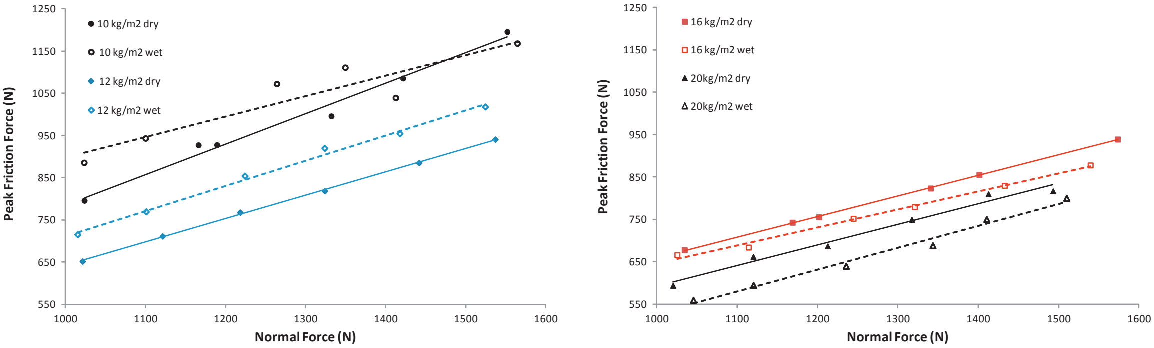

Fig. 4. Plots of peak friction force against normal force (with linear regression lines).

Figure 4 shows the relationships between static peak friction force and normal force. For 10 and 12 kg/m$^2$ sand infill, as normal loading increases, the dry surface was found to exhibit the lowest peak friction force. However, the opposite behaviour was observed with the 16 and 20 kg/m$^2$, which had a greater peak friction force in dry conditions. The average test velocities during the dynamic period of friction for each test are presented in Figure 3b. The average velocity (over all tests) varied from 0.092 m/s (wet - 1500N) and 0.116 m/s (dry - 1000N).

Table 2. Linear relationship coefficients showing effect of normal force applied on each friction parameter

| Surface | Peak friction force | | Average dynamic friction force | |
|---|---|---|---|---|
| | $R^2$ | $p$ | $R^2$ | $p$ |
| 10 kg/m$^2$ dry | 0.990 | $< 0.05$ | 0.992 | $< 0.05$ |
| 10 kg/m$^2$ wet | 0.925 | $< 0.05$ | 0.985 | $< 0.05$ |
| 12 kg/m$^2$ dry | 1.000 | $< 0.05$ | 0.994 | $< 0.05$ |
| 12 kg/m$^2$ wet | 0.997 | $< 0.05$ | 0.994 | $< 0.05$ |
| 16 kg/m$^2$ dry | 1.000 | $< 0.05$ | 0.998 | $< 0.05$ |
| 16 kg/m$^2$ wet | 0.997 | $< 0.05$ | 0.999 | $< 0.05$ |
| 20 kg/m$^2$ dry | 0.990 | $< 0.05$ | 0.984 | $< 0.05$ |
| 20 kg/m$^2$ wet | 0.992 | $< 0.05$ | 0.999 | $< 0.05$ |

Figure 5 shows the relationship between the average dynamic friction force and normal force. Strong and significant linear relationships were found for each surface condition. For 12 and 20 kg/m$^2$, the dry conditions exhibit lower average dynamic friction compared to wet. However, in an opposite trend, the 10 and 16 kg/m$^2$ dry condition develops greater dynamic friction as opposed to wet.

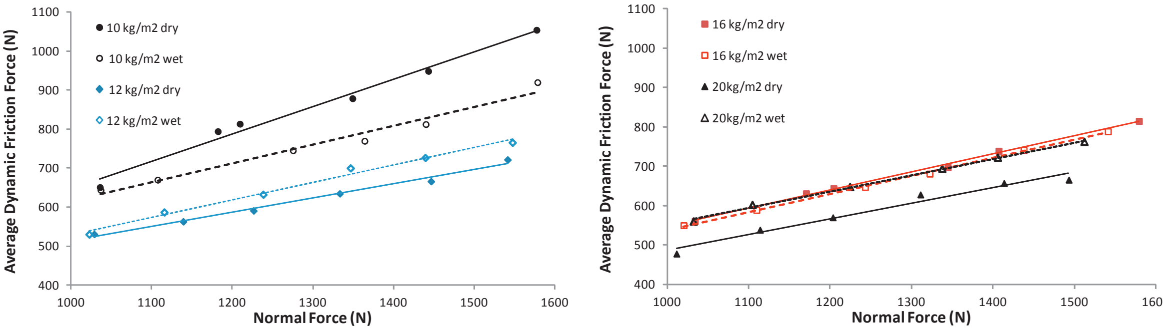

Fig. 5. Plots of dynamic friction force against normal force (with linear regression lines).

Significant main effects on three of the five perception conditions were reported. Figure 6 highlights that the 12 and 16 kg/m$^2$ volumes are significantly more predictable compared to 20 kg/m$^2$. It shows that 16 kg/m$^2$ is perceived to have significantly more grip compared to 20 kg/m$^2$, and that 16 kg/m$^2$ is statistically perceived to be harder compared to 20 kg/m$^2$.

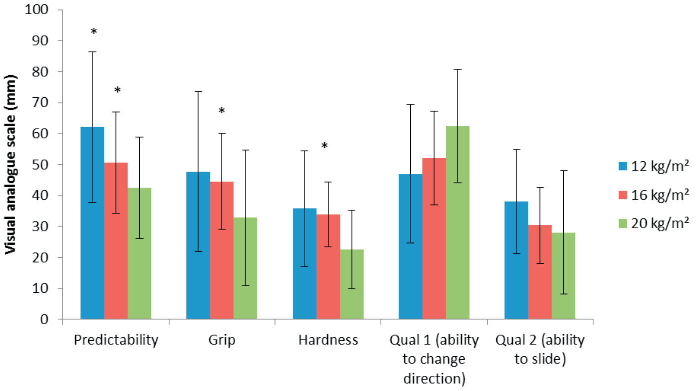

Fig. 6. Mean and SD for the perception conditions under dry conditions. Qual1 – lower the number = easier to change direction, Qual2 – lower the number = easier to slide.* denotes significant difference between

## 4. Discussion

The results presented demonstrate that the quantity of artificial clay significantly influences the friction developed at the shoe-surface interface. A study in which the effect of size particle on shoe-floor contact frictions is analysed is the one presented by Mills et al. (2009). In this investigation it is reported that particles with a bigger size are less likely to join and act as single entities. In contrast, dry small particles cohere, and act as a thin layer (Mills et al. 2009). In consequence this will affect the mechanical behaviour of the surface. Therefore, in our study the friction mechanism on the dry ACC surface is more likely to be influenced by inter-particle friction. For the 10 and 12 kg/m$^2$ conditions, the peak friction force is greater in the wet than the dry conditions. This is in agreement with Clarke et al. (2013) study. However, as the quantity of sand infill is increased on the surface, 16 and 20 kg/m$^2$, the behaviour is the opposite; the peak friction force is greater in the dry than the wet conditions.

Clarke et al. (2013) reported that during the dynamic period the moisture of the wet clay is lubricating the shoe-surface contact and inter-particle contact; hence reducing its resistance to dynamic shear. The dynamic period of the shoe sliding on the clay surface can be defined as a stick-slip. It was also observed that during the sliding period, sand particles were built up ahead of the shoe as described by Clarke et al. (2013). Therefore, the static and dynamic friction could be affected by this ploughing effect. In the future, this effect will be measured by further testing. In relation to perception, the 16 kg/m$^2$ perceived grip by the participants is in good agreement with our mechanical results under dry conditions, which show that this volume is higher in terms of peak friction force and average dynamic friction force compared to the values for the 20 kg/m$^2$ volume. This suggests that the players experience higher static and dynamic friction on the 16 kg/m$^2$ during the turning movement, and this is perceived by the participants as more grip compared to the 20 kg/m$^2$.

## 5. Conclusion

The experimental results demonstrate that the quantity of sand in an artificial clay court will significantly influence the friction developed at the shoe-surface interface. The findings of this study will therefore aid the understanding of tennis players' perceived response to a tennis court surface. In order to get a better understanding of friction behaviour, further testing needs to be performed on a wider range of samples, and once the tribological mechanisms involved are better understood, surface properties could be modified to increase performance and reduce injury risk.

## Acknowledgements

We thank the International Tennis Federation for all their technical assistance and valuable recommendations for this project.

## References

Clarke, J., Carré, M., J., Damm, L., Dixon, S., 2013. The development of an apparatus to understand the traction developed at thte shoe-surface interface in tennis. Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 227(3), 149-160.

Damm, L., Low, D., Richardson, A., et al. 2011. Modulation of tennis players' frictional demand according to surface traction characteristics. In: International society of biomechanics congress XXIII, Brussels, Belgium, 3–7 July.

Dixon, S.J., Batt, M.,E., and Collop, A.,C., 1999. Artificial playing surfaces research: a review of medical, engineering and biomechanical aspects. Int J Sports Med, 20(4): 209–218.

Guisasola, I., James, I., Stiles, V., et al., 2009. Dynamic behaviour of soils used for natural turf sports surfaces. Sports Engineering 12(3): 111–122.

Mills, R., Dwyer-Joyce, R.,S., and Loo-Morrey, M., 2009. The mechanisms of pedestrian slip on flooring contaminated with solid particles. Tribology International 42(3): 403–412.