

## DRAFT

# The Science of Sports Surface Interactions for Synthetic Turf Surfaces

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The introduction and acceptance of new (3<sup>rd</sup>) generation long pile filled synthetic turf surfaces in sports such as football and rugby has led to these surfaces becoming widely used at all levels of the game. The interaction of a sports person and/or ball with these surfaces is of great importance in terms of player safety, comfort and playing performance. The specification for these surfaces, and the constituent materials used, are known to vary within the industry. Recent field measurements of unfilled 'water based' pitches highlighted significant spatial and temporal changes in the playing characteristics both over the surface of a single pitch and between (similar) pitches, including the test results for traction. It has been suggested that synthetic turf surfaces increase the traction produced at the shoe-surface interface causing a greater number of sports specific injuries. However, as part of a PhD research programme at Loughborough University, a comprehensive review of published literature was performed which highlighted a significant lack of quantified research and data regarding the surface properties influencing the traction developed at the shoe-surface interface. There has been no attempt to date to measure and quantify the role of the individual components of a surface on the traction that can be achieved. If the underlying material science of the surface components were better understood, decisions and judgements based on the desired characteristics required for surfaces could be optimised. This paper reviews the available information regarding 3<sup>rd</sup> generation synthetic turf surfaces and establishes the primary parameters influencing traction during the interaction between a player and the surface, with a focus on the mechanics of the surface components and their interaction, and the influence of potential changes during the pitch lifetime, such as degradation. The proposed research and methods required to address these knowledge gaps is presented.

## Introduction

Since the introduction of the early versions of synthetic turf pitches, they have undergone technological development and have gradually become accepted in many sports and have largely increased in numbers. There are a wide variety of synthetic turf pitches available which can be designed for specific sports use or for multi-use. Most of these surfaces comprise of a similar pitch system including a synthetic carpet laid over or sometimes bonded to a shockpad, which in turn is laid over an engineered sub-base as shown in Figure 1. The main differences between pitch systems comes in the form of the carpet and shockpad layers. The synthetic carpet and shockpad layers form the surface system and together provide the player/surface and ball/surface characteristics and it is these interactions which are of great importance in terms of player safety, comfort and playing performance. There are a number of manufacturers and installers of synthetic turf pitches all using different materials and installation techniques providing a wide variety of possible pitch systems all displaying slightly different mechanical characteristics. It is therefore inevitable that these variations of pitch systems produce different performance characteristics, which may not all be favourable to a specific sport and the comfort and safety of the players.

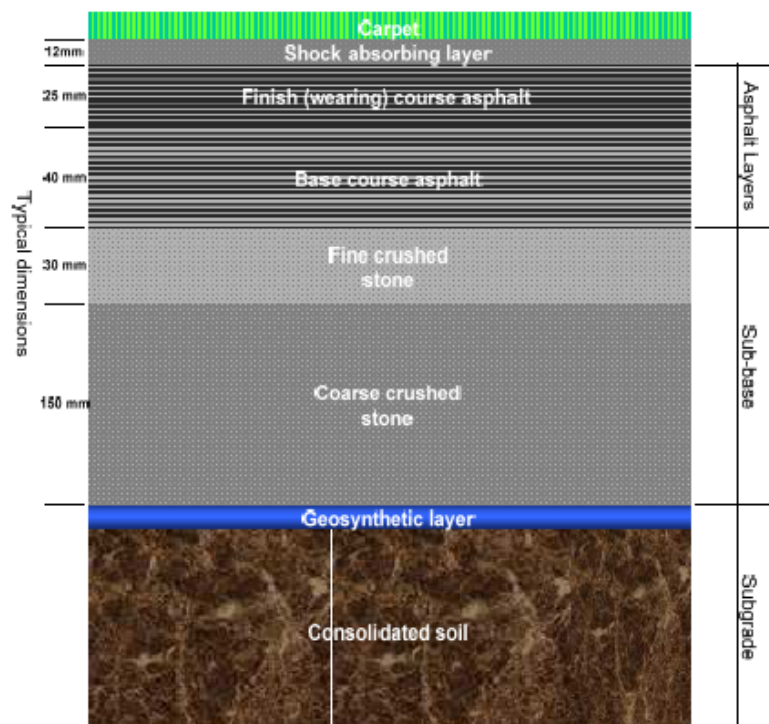


Figure 1: A typical construction profile of a synthetic turf surface.

A recent development in synthetic turf pitches has seen the introduction of the long pile carpet with fibres less densely packed varying between 35 mm and 65 mm in length with a rubber crumb infill or a combination of sand and rubber crumb. This has become commonly known in the sports surface industry as the third generation or 3G. This surface is intended to better simulate natural turf. The improved qualities of these long pile surfaces have been recognised by the international governing bodies of football and rugby union and they have both amended

their rules to allow their sport to use synthetic turf pitches for training purposes and in the case of football some competitions. The introduction and acceptance of third generation artificial sports surfaces in football and rugby has led to these surfaces becoming widely used at all levels of the game.

A main focus currently in the literature relating to synthetic turf pitches are the interactions of sports shoes and playing surfaces that maybe related to injury. It has been suggested that synthetic turf surfaces increase the traction produced at the shoe-surface interface causing a greater number of sports specific injuries (Nigg and Segasser, 1988; Valiant, 1990; Milburn and Barry, 1998; Bonstingl *et al*, 1975 and McCarthy, 1989). More recently however, research has contradicted these earlier assumptions and it has been suggested that the true cause of sports specific injuries is not known. The main reason for this being the large and complex number of variables involved at the player-surface interface. As part of a PhD research programme at Loughborough University, a comprehensive review of published literature was performed which highlighted four main primary parameters influencing the overall traction properties produced at the shoe-surface interface. They are; the biomechanics of the athlete, footwear, the surface and the environment. Individually and ultimately together these parameters all affect the traction produced at the shoe-surface interface.

This paper reviews the available information regarding 3rd generation synthetic turf surfaces and establishes the primary parameters influencing traction during the interaction between a player and the surface, with a focus on the mechanics of the surface components and their interaction. The proposed research needs and methods required to address these knowledge gaps are presented.

## **A Review of Literature**

A comprehensive review of published literature was performed providing available information regarding 3rd generation synthetic turf surfaces and establishes the primary parameters influencing traction during the interaction between a player and the surface. The main points are:

### **Player-Surface interactions**

Many sports such as football, rugby, hockey and American football use sport specific footwear which comprises of cleats or studs on the underside of the shoe. During sports movements these cleats or studs penetrate and interlock with the playing surface creating traction forces. This ability to generate traction between a player's footwear and a sporting surface is a crucial factor influencing the player's performance. The magnitude of the traction force contributes to the balance of an athlete and their ability to accelerate or decelerate and change direction. The maximum traction force achievable for a given shoe-surface combination is dependent on a number of interacting parameters operating at the interface between the footwear and the

sports surface. An understanding of these parameters, and the processes involved is necessary if performance is to be optimised either by footwear selection/design or management of the sports surface. Traction can be subdivided into two forms; translational (resistance to sliding) and rotational (resistance to turning), although they often occur simultaneously.

### **Injuries**

There is some disagreement in the current literature as to the different factors of sports shoes and playing surfaces that have been concluded to be related to injury. It is thought by many that the introduction of artificial sports surfaces has increased the traction properties between the sports shoe and surface and this is the main cause for certain sports specific injuries at the knee, ankle and foot. An athlete must compromise between achieving a high enough level of traction on the playing surface to allow for acceleration and deceleration and turning manoeuvres, whilst avoiding too high a traction that the foot is fixed in place and thus transmits a torsional force to the lower limb that is great enough to cause damage. Many injury studies have compared injuries obtained on synthetic turf surfaces to that of natural turf. There are however, limited studies that have actually quantified specific injuries directly related to artificial surfaces. More recent research has indeed contradicted these earlier assumptions with the main causes of injury being overuse due to the greater consistency of these surfaces and the ability to play on artificial surfaces for longer periods of time (Meyers and Barnhill, 2004; McCarthy, 1989 and Dixon *et al.*, 1999). However, the earlier findings may be a reflection of the traditional synthetic materials such as nylon, which may exhibit very different frictional properties compared to the newer generations of artificial surfaces being installed today. If more were known about the parameters influencing the traction properties produced at the shoe surface interface, measures could be taken to reduce the likelihood of injury occurrence without compromising the athlete's ability to perform to the best of their ability.

### **Primary parameters influencing traction:**

Studies have identified that the traction produced at the shoe-surface interface is specific to the chosen shoe-surface combination (Torg *et al.*, 1974; Heidt *et al.*, 1996; Cawley, 2003; Livesay, 2006; Gheluwe *et al.*, 1983), although there has been a lack of interpretation by researchers as to why this is. A complete understanding of the complex and large number of interactions at the shoe-surface interface remains elusive.

Suggested primary parameters in determining the traction properties produced at the shoe-surface interface derived from the literature review are:

- A) The biomechanics of the athlete
- B) Sports specific footwear
- C) The playing surface
- D) Environmental factors

Each of these primary parameters consist of a number of variables which may all individually contribute to the overall traction properties produced at the shoe-surface interface. It is therefore imperative that these variables are understood as well as their interaction with others. Table 1 highlights some of the possible variables within each primary parameter that may effect the traction properties at the shoe-surface interface based on information gained from the literature.

Table 1- Summary of primary parameters influencing traction and their variables.

<b>Biomechanics</b>	<b>Footwear</b>	<b>Surface</b>	<b>Environment</b>
Actual Movement	Number of Studs	Physical Characteristics of the Fibre	Water
Mass of Athlete	Stud Configuration	Physical Characteristics of the infill	Temperature
Loading Rate	Size of Stud	Mechanical properties of the Fibre	Humidity
Angle of Foot	Shape of Stud	Mechanical Properties of the Infill	Chemicals
Speed of Athlete	Stud Material	Composite Material Properties	Maintenance
Height Before Contact	Contact Surface Area		Usage

These four areas will now be discussed further in order to gain a better understanding of how they might influence the overall traction properties produced at the shoe-surface interface.

### **The Biomechanics of the Athlete**

Early studies of traction analysed findings based on the classic laws of friction observing the traction properties produced by a shoe-surface combination to be directly proportional to the normal force applied (Torg et al., 1974). Several authors however, suggest that classical laws of friction cannot be considered for shoe-surface combinations in sport, as these laws apply to dry and homogeneous surfaces in contact, and do not explain the interactions between compliant, resilient, viscoelastic, non-uniform surfaces (Milburn and Barry, 1998; Shorten, 2003 and Brown, 1987). Studies by Nigg (1990), Cawley et al., (2003) and Gheluwe et al., (1983) indeed have found that traction developed at the shoe-surface interface is significantly influenced by changes in the normal force applied and a non linear relationship between the load applied and the resultant level of traction is produced. When determining traction characteristics of a shoe-surface combination it is therefore desirable to measure these traction properties at a similar magnitude to those observed in a real game.

On the field of play when an athlete plants their foot and decelerates prior to making a sports specific movement, the inertia and momentum of the body generate very high compressive forces between the shoe and the playing surface as the momentum carries the body over the foot. These high compressive forces can also be described as ground reaction forces and are functions of a number of factors such as the mass of the athlete, the loading rate, running

speed, contact area of the foot on the surface, all of which have shown to effect the traction properties at the shoe-surface interface (Bostingl et al., 1975; Gheluwe et al., 1983; Nigg and Yeadon, 1987; Valiant, 1990; Cawley, 2003). There has been some discrepancy in the literature between forces measured, which is likely to be due to different running speeds and the mass of an athlete. Secondly, the measuring techniques and methodology used in these studies all differ, which may have resulted in slightly different movements by the human subjects resulting in different ground reaction forces being measured. As there has been no clearly defined forces generated by specific sports movements many researchers have studied the traction properties produced at the shoe-surface interface by varying loads, which may or may not be realistic. It is therefore important to determine realistic body weights, rates and angles of loading and running speeds of players for specific movements. There is currently a number of studies aiming to achieve these conditions but to date there is no agreed set of conditions.

### **Sport Specific Footwear**

Torg and Quedenfeld (1974) were among the first researchers to document the important role of footwear in being one of the primary parameters influencing traction properties produced at the shoe-surface interface including variables such as the number, length and diameter of cleats or studs. These variables together with evidence that the material of the footwear and the area in contact with the playing surface influence the resultant traction properties introduces even more complexity into the measurement of traction.

Several investigators have speculated regarding safe and unsafe friction coefficients for football shoes. Cawley et al (2003) and Livesay et al (2006) however, suggest that these speculations and generalisations are difficult to make until correlations between forces generated at the foot can be clearly identified and secondly, that the performance of a given cleat may change on different playing surfaces as different surfaces will vary in the traction properties that they produce.

The majority of literature investigating the traction properties of sports specific footwear have looked at a variety of shoe types and surface types concluding that the traction generated at the shoe-surface interface is specific for each combination. However, there has been little or no attempt to try and understand why this may be until more recently. A study by Kirk et al., (2006) have begun to better understand the factors of footwear that influence traction using neural networks. This type of modelling is still in development however, and questions arising from the study are the lack of surface boundaries included in the model. Without a surface specification the information obtain is only of limited use. Secondly, the network was only based on 22 experimental measurements. In order for this to become a reliable tool, more data is required.

## The Playing Surface

It is the authors interpretation that there are numerous products available all exhibiting slightly different properties due mainly to variations in the carpet and infill layers of a synthetic turf surface, some of which may influence the level of traction produced at the surface. Table 2 further breaks down the surface properties and characteristics that may affect the overall traction produced at the surface. There is limited data available on traction produced at the shoe-surface interface with regards to sports surfaces especially for newer synthetic turf surfaces.

Table 2- A breakdown of the playing surface variables influencing traction.

<b>Surface Layer</b> (related to columns two and three)	<b>Physical Characteristics</b>	<b>Mechanical Properties of Individual Components</b>	<b>Composite Material Mechanical Properties</b> (Pitch System)
<b>Fibre</b>	Pile Height	Compressive Behaviour	Traction (Rotational/Translational)
	No. of Tufts per Unit Area	Surface Roughness	Hardness
	Fibre Material	Friction	Resilience
	Fibre Width	Tensile Strength	Stiffness
	Pile Weight		Penetration Stiffness
<b>Infill</b>	Material	Compaction (Bulk Density)	Tuft Withdrawal Force
	Size	Compression	Shear Strength
	Shape	Stiffness	
	Grading	Friction (Shear Strength)	

The variety of fibres and manufacturing processes of pile, infill, shock pads and installation techniques suggests that it is inevitable that substantial differences in the properties of the overall systems exist. The composition and construction of these products will influence their behaviour. To try and limit the differences between pitch systems, sports governing bodies have implemented performance requirements that a surface must achieve for a specific sport to be played on the surface including traction properties. Although these requirements have reduced the differences in playing characteristics between surfaces there has been no attempt to try and quantify the individual components of a surface.

Previously many authors have suggested that the properties of artificial turf have led to an increase in the frictional properties observed between a shoe-surface combination. Shorten et al (2003) tested four different surfaces to compare the traction properties of natural turf, unfilled artificial turf and a long pile in-filled artificial turf. The results showed the turfs with a rubber and a rubber/sand infill showed a significantly higher translational traction and a lower resistance to rotation, similar to that of the natural turf. With a higher resistance to rotational traction, artificial turfs have been linked to non-contact ACL injuries in football. However, as these long pile filled surfaces seem to produced more natural turf like properties, studies linking synthetic turf to higher injury rates may not apply to these surfaces. In reality there has

been little research into the science of synthetic turf surfaces and the properties influencing traction at the shoe-surface interface. It could be assumed that previously the interest in surfaces lay in the comparison between natural turf and artificial surfaces and so this is where research has focused. However, the wide acceptance of these surfaces for use in many sports suggests that there is now a greater need to better understand the underlying science of these surfaces.

### **Environmental Factors**

There is evidence to suggest that individually environmental factors such as water may influence the traction properties at the shoe-surface interface (Torg et al., 1974; Bowers and Martin, 1975; Heidt et al., 1996). However, it is a combination of these environmental factors that inevitably cause a synthetic turf surface to degrade resulting in changes to the properties and behaviour of a surface. Recent field measurements of unfilled 'water based' pitches highlighted significant spatial and temporal changes in the playing characteristics both over the surface of a single pitch and between (similar) pitches, including the test results for traction (Severn et al., 2007). There is however, a general lack of quantified research and data on the degradation of synthetic turf surfaces based on the review of literature. This is more apparent for third generation surfaces, possible due to their recent inclusion into the synthetic turf surface market. There is limited knowledge as to how the mechanical behaviour (the properties of the surface that influence playing characteristics) of a synthetic turf surface changes with time and usage and whether surfaces can maintain performance requirements set by sports governing bodies.

### **Discussion**

The review of literature has identified that the relationship between the biomechanics of a specific sports movement to produce the required traction characteristics at the shoe-surface interface have been quantified in a limited manner by researchers. To provide accurate measurements of traction these boundary conditions must be known.

Sports footwear has been a focus in the literature. It could be assumed that this is the largest commercial area in the industry with branding and money to spend on research. However, the large volume of research was unable to provide real scientific knowledge as to why varying footwear and studs provide different traction properties.

There has been a significant lack of quantified research and data regarding the surface properties influencing the traction developed at the shoe-surface interface. There has been no attempt to date to measure and quantify the role of the individual components of a surface and their interactions on the traction that can be achieved and the influence of degradation. If the underlying material science of the surface components were better understood, decisions and judgements based on the desired characteristics required for surfaces could be optimised.



The literature review has demonstrated that the primary parameters determined individually all have an effect on the traction properties displayed at the shoe-surface interface. However, it is how they work together to provide the overall level of traction that is important and needs to be better understood. Many researchers of traction have only investigated one or sometimes two parameters affecting traction at the shoe-surface interface. This in part is largely due to the vast number of variables involved making it a very complex measurement. However, in order to accurately measure traction all the above parameters and their variables must be considered.

### **Research Needs**

This review of literature has covered many aspects of synthetic turf surfaces and throughout has highlighted the need for further research. The research needs for this project therefore are focused on the general lack of scientific knowledge and evidence regarding synthetic turf surfaces.

A greater understanding of how the properties of a pitch system influence the traction produced during the interaction between a player and the surface is required. To achieve this a framework for characterising, classifying and measuring a synthetic turf pitch and its components is needed so that key properties can be identified and evaluated. A greater understanding of how these key properties identified interact together as a pitch system is also required to allow a benchmark pitch system to be determined. An evaluation of current test methods for their usefulness in assessing pitch components, behaviour and performance is therefore required, with a focus on the test methods used to measure traction. A test programme to objectively evaluate and classify physical and mechanical changes of a surface to better understand the influence of degradation on traction produced by a surface needs to be developed.

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