SYNTHETIC TURF IN THE USA – TRENDS AND ISSUES

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ABSTRACT

The rate of installation of synthetic turf fields in the USA is expected to increase by 20% annually over the next four years. Driving this current expansion are the new configurations of synthetic turf surfaces termed 'infill' systems. The long-term durability of synthetic infill systems is unknown. Limited research has been done on the safety and playability of these surfaces. The limited data available suggest that the infill systems exhibit lower surface hardness, better traction characteristics, and are less abrasive than traditional synthetic turf. When exposed to sunlight, synthetic turf systems heat up much faster than natural turfgrass. Currently, research is being conducted to determine if the surface and air temperatures of infill synthetic turf systems can be effectively cooled using irrigation. Infill synthetic turf systems require maintenance (grooming) including brushing to keep the pile fibers upright and loosening of the granules to keep the surface from becoming hard. Limited data suggest that grooming improves playing surface quality. Infill synthetic turf systems and the companies marketing them are changing rapidly as is the methodology used to evaluate these surfaces. Presently, these infill synthetic turf systems seem to have better playing quality characteristics than traditional synthetic turf and have an important place in helping athletic field managers provide safe playable multipurpose fields year round.

Keywords

artificial turf, athletic fields, crumb rubber, Fieldturf, infill, injuries

INTRODUCTION

With 40 years of use, synthetic turf playing surfaces have come full circle in their application. Chemgrass, the precursor to Astro Turf, was initially developed in the early 1960s as a way to provide inner-city youth with a suitable surface for play grounds, etc. (Morehouse, 1992). However, during the 1970's and 1980's traditional synthetic turf surfaces were primarily installed at high-end facilities such as premier high school, college, and professional stadiums. With the increasing diversity of participatory sports, the development of improved synthetic surfaces and competition between multiple synthetic turf companies has resulted in a significant reduction in cost. Therefore, the new synthetic turf systems are being installed not just in high-end professional stadiums but in grade schools and municipal fields across North America. In 2003, approximately 400 synthetic turf fields were installed in the United States with an additional 550 installations projected for 2004 (D. Gill, 2004, personal communication). The vast majority of these installations are not replacements of traditional synthetic turf surfaces but are either new installations, where no field previously existed, or a transition from a natural turfgrass surface to a synthetic surface.

These new synthetic surfaces are comprised of a horizontal backing supporting numerous vertical nylon, polypropylene or polyethylene fibers. These vertical fibers (pile) are much longer than those of traditional synthetic turf and can be filled with varying types of granulated material (infill media), typically sand and crumb rubber. The first infill system contained 100% sand infill media and was invented by an American, Frederick T. Haas, Jr., in 1976. However, the concept was first applied and developed in England. Omniturf was one of the widely known sand filled infill systems (Morehouse, 1992). Because the all-sand infill provided little cushioning, a shock absorbing pad was typically installed below the horizontal backing.

The 1997 installation of a synthetic turf field (brandname FieldTurf), at Ringgold High School Monongahela, PA, USA using a combination of sand and granulated (crumb) rubber infill media marked the beginning of the latest period of expansion for synthetic turf athletic fields in the United States. As many of the initial installations of synthetic turf systems containing crumb rubber and crumb rubber/sand infill media reach the end of their warranty periods, the industry expects an even greater increase in installations due to the wait and see attitude of a large number of potential customers. The rate of installation of synthetic turf fields is expected to increase by 20% annually over the next four years. (R. Anderson, 2004, personal communication).

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It is believed that these new infill systems provide athletes with a surface that performs more like natural turfgrass than traditional synthetic turf (Popke, 2002); however, the long-term durability of these fields is unknown. The duration of the warranties offered by synthetic turf companies has been set by economic and competitive issues as opposed to knowledge of the long-term durability of the systems. Originally, the standard warranty of a crumb rubber infill synthetic turf system was five years. Competition increased the warranty to eight years and for several projects the systems were warranted for 10 years. Currently, an eight-year warranty is considered standard in the United States. This author has seen some outdoor high-use fields that may last well beyond the warranty period while others look worn after only one year of use. Since the pile fibers breakdown due to both foot traffic and photodegradation, indoor fields will typically outlast fields that are exposed to sunlight. The author has observed thinning pile fiber in high wear areas around the goal mouth of high school lacrosse fields after only two years of use.

The Synthetic Turf Council (Daulton, GA) is a non-profit organization formed to set minimum quality standards for synthetic turf manufacturing and use in the United States. The council is currently wrestling with the issue of warranty duration and is considering suggesting some guidelines on system warranties (Synthetic Turf Council, Inc., 2003). Of critical importance to the consumer when trying to select an infill system is to consider whether that company will still be in business throughout the duration of the warranty. Some of the companies representing an infill synthetic turf system have already gone out of business in the United States. Of considerable note was the closure of SRI, Inc. owner and manufacturer of AstroTurf, AstroPlay, and NexTurf. From the 1970's through much of the 1990's this company was the largest manufacturer and installer of synthetic turf systems in the United States.

CURRENT ISSUES

Besides the long-term durability of infill systems, a number of other issues exist concerning infill synthetic turf systems. These issues can be grouped into four categories: athlete performance and safety, surface temperature, gravel base construction and maintenance procedures.

Athlete Performance and Safety

Numerous studies have been conducted to evaluate the safety and playability of traditional (non-infill) synthetic turf surfaces. Three methodologies are used to compare the safety and performance of various surfaces. These include 1) material tests where mechanical devices simulate human movement and measure the associated forces; 2) human performance tests where researchers measure the forces associated with the interaction of a human subject and a surface; and 3) epidemiological studies in which the number and type of injuries sustained by athletes during actual sporting events are counted.

Material tests have been completed that measure the shoe-surface traction and surface hardness of synthetic turf surfaces (Bowers and Martin, 1975; McNitt and Petrunak, 2001; Valiant, 1990). Human subject tests have shown improved athlete performance on traditional synthetic turf when compared to natural turfgrass (Krahenbuhl, 1974; Morehouse and Morrison, 1975) and epidemiological studies have counted the number of knee and ankle injuries on synthetic versus natural turfgrass (Meyers and Barnhill, 2004; Powell and Schootman, 1992; Powell and Schootman, 1993).

No large-scale epidemiological studies have been published comparing the number of surface-related injures sustained by athletes playing on infill synthetic turf systems to the number of injures sustained on either traditional synthetic turf or natural turfgrass surfaces. One study (Meyers and Barnhill, 2004) compared injury incidence of eight high school (American) football teams in Texas USA playing on infilled synthetic surfaces (FieldTurf) and natural turfgrass surfaces. Although similarities in injury occurrence existed between FieldTurf and natural grass fields over a five-year period of competitive play, there were significant differences in injury time loss, injury mechanism, anatomical location of injury, and type of tissue injured between playing surfaces. The researchers reported higher incidences of 0-day time loss injuries, noncontact injuries, surface/epidermal injuries, muscle-related trauma, and injuries during higher temperatures on FieldTurf compared to natural turfgrass surfaces. Higher incidences of 1- to 2-day time loss injuries, 22+ day time loss injuries, head and neural trauma, and ligament injuries were recorded on natural turfgrass fields compared to FieldTurf. The researchers state a number of limitations to their study including the random variation in injury typically observed in high-collision team sports and the percentage of influence from risk factors, other than simply surface type. Field conditions at the time of injury were not measured although the researchers noted that the majority of injuries (84.4%) occurred on natural turfgrass surfaces under conditions of no precipitation (dry surface).

The United States National Collegient Athletic Association (NCAA) is collecting injury data from numerous men's and woman's sporting events across the United States using a computerized system called " NCAA Injury Surveillance System" (National Collegiate Athletic Association, 2004) but presently does not have sufficient data from which to draw conclusions (R. Dick, 2004, personal communication).

Stefanyshyn et al. (2002) used human performance comparisons to evaluate 20 configurations of infill synthetic turf systems. Human subjects performed various maneuvers on the surfaces and the forces associated with

Table 1. Mean maximal free moment of rotation (M_{max}), translational friction coefficients, maximal vertical impact forces (Fz_{max}) and impact loading rates, using a Nike soccer shoe Stefanyshyn et al. (2002).

	Mmax	Trans. Friction Coeff.	Fzmax	Max Loading Rate
	(Nm)	(μ)	(N)	(kN/s)
Range	26.3 - 35.2	1.04 - 1.85	1019-1343	26.4-37.8

the cleated foot interacting with the surface were recorded in the laboratory using a force plate installed beneath the turf surface. Stefanyshyn et al. (2002) reported a significant range of traction and surface hardness differences among the infill synthetic surfaces (Table 1) and grouped the 20 infill surfaces into categories of highly recommended, recommended, and not recommended based on surface hardness and both the rotational and translational (linear) traction recorded on these surfaces.

Shorten et al. (2003) performed material tests in which weighted shoes were dragged across varying infill synthetic turf systems and traditional synthetic turf. The translational and rotational traction of the various shoe-surface combinations were measured. The researchers concluded that both shoes and surfaces significantly affect traction. On all surfaces tested, shoes with lower profile cleats or studs had better overall traction performance compared to shoes with longer cleats and infill systems had better traction performance than traditional synthetic turf. Traction performance was calculated using an index where rotational traction values were subtracted from translational traction values. To eliminate scaling and range differences between the translational and rotational resistance measures, calculations were done using "standard scores" rather than raw data. The standard score is a measure of where a particular result lies relative to the average and distribution of all the results recorded: ex. Standard Score = (Actual Score - Average Score) / (Standard Deviation of All Scores). The researchers stated that further research is required to determine the effects of moisture, temperature and ageing on surface traction performance. Both the study by Stefanyshyn et al. (2002) and the study by Shorten et al. (2003) were performed on newly constructed infill systems in a laboratory setting.

It is common knowledge that, when fallen upon, traditional synthetic turf is more abrasive to an athlete than natural turfgrass. The American Society of Testing and Materials (2002) have a standard method (ASTM F1015-02) that evaluates the relative abrasiveness of a synthetic turf surface by pulling friable foam blocks attached to a weighted platform over the playing surface in a prescribed manner. The weight of foam abraded away determines the relative abrasiveness of the surface. McNitt and Petrunak (2004) report that infill synthetic turf systems vary somewhat in their relative abrasiveness but on average have an abrasiveness index of about half that of traditional synthetic turf (Table 2). To date ASTM F1015-02 has been used by private firms to evaluate their own products, but no published data exist from other researchers using this method.

Table 2. Abrasion index of synthetic turf surfaces.

Treatment	Abrasion Index[1]
Astroplay	29.0
Astroturf	56.4
Fieldturf	32.3
Nexturf	25.3
Omnigrass 41	31.6
Omnigrass 51	31.8
Sofsport	32.2
Sprintturf	31.4
LSD (p=0.05)	3.5

[1] Abrasion index is determined by pulling foam blocks in a weighted sled across the plots in 4 directions and determining the loss (by weight) of the blocks. Abrasiveness index = [(starting block weight - final block weight)/6] *100.

Surface Temperature

One of the negative factors regarding any synthetic turf surface is the high temperatures experienced by athletes using these fields on sunny days. Researchers have found that the surface temperatures of synthetic turf playing surfaces are significantly higher than natural turfgrass surfaces when exposed to sunlight (Buskirk et al., 1971; Koon et al., 1971; and Kandelin et al. 1976). Buskirk et al. (1971) found that, the surface temperatures of traditional synthetic turf were as much as 35-60°C higher than natural turfgrass surface temperatures. Buskirk et al. (1971) placed thermocouples on the inner soles of cleated shoes and had individuals walk on the synthetic surface to determine the amount of heat transferred directly from the surface to the individuals' foot. Any heat gain to the foot must be dissipated by blood flow. Buskirk et al. (1971) concluded that the heat transfer from the surface to the sole of an athlete's foot was significant enough to contribute to greater physiological stress that may result in serious heat related health problems.

Surface temperatures of infill synthetic turf systems have been reported to be as high as 93°C on a day when air temperatures were 37°C (Brakeman, 2004). Researchers at Brigham Young University measured the surface and air temperature above an infill synthetic turf system before and for a period of time after water had been applied through irrigation (Brakeman, 2004). The researchers reported that after 30 minutes of irrigation the surface temperature was lowered to that of a nearby natural turfgrass surface (29°C). However, the researchers reported that the surface temperature rose very quickly and within 5 minutes had risen to 49°C. This rapid rise in temperature could be due to the lack of through wetting of the infill media, which was found to be hydrophobic. This author personally observed this field on May 19, 2004. The infill media was very hydrophobic and water was observed to bead-up and run over the surface rather than penetrate. After a 10-minute irrigation cycle, water was observed to be moving laterally over the surface while the infill media was only wet to an average depth of 1 - 2 mm. The use of a non-ionic wetting agent may help to alleviate this problem. The author has never observed this phenomenon on another field and has no reports of others observing this phenomenon.

Morehouse (1992) suggests that the evaporation of 1.2 L m^{-2} h^{-1} of water should be sufficient to cool a traditional synthetic surface to a level near that of a natural turfgrass surface and notes that water routinely applied to synthetic surfaces, used for women's field hockey to slow ball bounce, will dampen the surface for at least one-half game even under favorable evaporative conditions (i.e. elevated air temperature and brisk air movement). The amount of water suggested for application prior to a field hockey event is 8,000 to 10,000 L spread evenly across a 105 m x 64 m surface. In an ongoing study of the effect of irrigation on infill synthetic turf systems, McNitt (unpublished data) observed that after equal quantities of irrigation were applied to the surfaces, traditional synthetic turf remained damp for a longer period of time than nine infill synthetic turf systems. These results indicate that the formula Morehouse (1992) suggested for water application to traditional synthetic turf may not be applicable to infill systems. More research is needed on the effects of irrigation on the temperatures and the relative humidity experienced by athletes performing on these surfaces. Studies are currently being conducted by researchers at Penn State and Iowa State Universities to determine the effects of pre-game irrigation on the athletes' playing environment.

Gravel Base

Poor surface grading and lack of internal drainage are the two main construction problems encountered in infill synthetic turf systems in the USA. Currently, there are no standard specifications for drainage gravel installed beneath the backing of an infill system. The lack of an agreed standard has resulted in numerous installations with poor quality gravel that is either hard to grade to desired tolerances or that allows little internal drainage after compaction. The Synthetic Turf Council was formed in 2002 in order to produce a set of minimum specifications that will protect consumers from installations of poor quality synthetic turf infill systems (Synthetic Turf Council Inc., 2003). Currently, the council specifies that the sub-base drainage gravel of a synthetic turf field should provide adequate drainage and stability; however, a gravel particle size distribution is not specified. Subcommittees within the Synthetic Turf Council and in the F.08 division of ASTM are currently working on sub-base gravel specifications.

Often, a failed gravel base installation begins with a coarse uniform gravel nearly free of fine particles. The grading contractor becomes frustrated attempting to meet the grading tolerances specified using such a coarse stone or is unsatisfied with the stability of the surface caused by the uniformity of the gravel particle size distribution. The contractor then gains permission to add a non-uniform sand/fine gravel mix that is either incorporated into the surface layer of gravel or applied as a topdressing. The addition of a non-uniform aggregate is often determined to be the cause of poor gravel base drainage. A standard test for in situ water infiltration into synthetic turf has been specified in ASTM F1551-94 (American Society of Testing and Materials, 1994). This method was developed for traditional synthetic turf and is not applicable to infill synthetic turf systems as the method allows significant lateral flow through the infill media. A subcommittee of ASTM F.08 division is currently investigating alternative methods to measure the in situ water infiltration rate into an infill synthetic turf system.

Maintenance

Maintenance of infill synthetic turf systems initially received little consideration by consumers as the systems were being marketed as almost maintenance free. Static electricity, especially when the surface is relatively new, can cause the crumb rubber infill media to cling to the pile fibers. This causes a temporary discoloration of the surface and is aesthetically displeasing. Field managers have had success reducing the static effect with applications of dilute fabric softeners to the surface several days prior to an event.

Maintenance is required on infill systems as foot traffic causes the pile fibers that extend above the infill media to mat down and appear off color. Matting may affect the traction experienced by athletes (McNitt and Petrunak, 2004). Foot traffic can also cause the infill media to become settled resulting in a harder surface. Procedures have been developed to correct the pile matting and infill media settlement. The term 'grooming' has been used to describe these maintenance procedures. Grooming has two components brushing and loosening of the granules.

Brushing is typically done once per week using either a pull behind tennis court broom or a powered rotating drum with bristles in order to stand the pile fibers upright. Fields in the United States are being brushed with non-powered pull-behind units because power brushing is believed to cause additional wear on the pile. Some athletic field managers are only brushing the fields when the surface is wet in order to reduce the wear due to friction of the broom on the pile fiber. Some field managers

Table 3. Surface hardness (Gmax) of infill systems determined with the Clegg Impact Soil Tester prior to and after grooming.

Treatment	Pregrooming	Postgrooming
Astroplay	58.1	44.0
Astroturf	118.6	78.5
Fieldturf	78.4	57.4
Nexturf	53.7	52.3
Omnigrass 41	70.6	50.4
Omnigrass 51	53.4	38.8
Sofsport	78.5	56.4
Sprintturf	101.2	65.2
LSD (p=0.05)	10.2	3.5

are brushing with a wetted piece of traditional synthetic turf turned upside down.

The loosening of the granules is accomplished using either spring tines attached to the brooming unit or slicer/spiker units pulled behind a utility cart. Loosening of the infill media has been shown to significantly reduce surface hardness (McNitt and Petrunak, 2004)(Table 3). There are reports that some infill systems have become unacceptably hard and it is often found that these fields were not groomed on a regular basis.

Tools used to loosen the granules include devices like the spring tines on the GreensGroomer (Indianapolis, IN). The spring tines on these devices are not preferred by most field managers in the USA. The managers claim that grooming with a spring tine unit results in numerous pile fibers being removed. Most field managers prefer to loosen the granules with a slicer device equipped with numerous vertical star shaped non-powered blades that roll over the surface. As the blades roll over the surface the points of the blade penetrate and loosen the infill media.

INFILL SYNTHETIC TURF RESEARCH AT PENN STATE

In order to evaluate the effects of grooming on the playing surface characteristics of varying infill synthetic systems, a study was begun at The Pennsylvania State University in the fall of 2002 (McNitt and Petrunak, 2004). The Penn State study is designed to compare the playing surface quality of natural turfgrass, traditional synthetic turf, and various infill systems over time. Surface quality will be periodically evaluated as the systems are exposed to weather and simulated foot traffic. The various surfaces are being evaluated for surface hardness, traction, abrasiveness, temperature, and matting.

Surface Hardness

Surface hardness is being measured with the ASTM F1702 method (Clegg Impact Soil Tester or CIST) equipped with a 2.25 kg missile and a drop height of 455 mm (American Society for Testing and Materials, 2000a) and the ASTM F355 method equipped with a 9.1 kg missile and a drop height of 610 mm (American Society for Testing and Materials, 2000b). The ASTM F1702 method is the standard method to measure the surface hardness of natural turfgrass playing surfaces in the USA while the ASTM F355 method is the standard method for measuring the surface hardness of synthetic playing surfaces. Both methods measure impact attenuation using an accelerometer mounted on the missiles, and is reported as Gmax, which is the ratio of maximum negative acceleration on impact in units of gravities to the acceleration due to gravity. According to historical data, the value of 200 Gmax as measured using the F355 is considered to be a maximum threshold to provide an acceptable level of protection to users and has been accepted by the U.S. Consumer Product Safety Commission. Additional rationale for this upper limit can be found in ASTM F1936 (American Society for Testing and Materials, 2000c). In year one of the Penn State study all of the infill systems measured well below the maximum level of 200 Gmax even after the equivalent of 96 games of simulated traffic using the Brinkman traffic simulator (Cockerham and Brinkman, 1989).

Although the missiles used in both methods are different, McNitt and Petrunak (2001) reported that under the conditions of their study the relationship between the Gmax values generated by the F355 method can be compared to the values generated by the F1702 method (CIST) using the regression equation F355 x 0.66 - 9.3 = CIST. The regression coefficient for this equation was 0.95. Although this study was limited to the Sofsport infill system, the high regression coefficient would indicate that the CIST would be a suitable and relatively inexpensive device that field managers could use to monitor the surface hardness of Sofsport installations.

Grooming lowered the surface hardness of all treatments in the Penn State study. Grooming consisted of loosening of the infill media using a 40" Lawn aerator (model # 45-0296 Agri-fab, Inc. Sullivan, IL) equipped with numerous vertical star shaped non-powered blades that roll over the surface. Two passes with the lawn aerator were carried out on each plot with the second pass being 90° to the first. Following the aerator passes, the pile above the infill material was brushed using a hand held power broom to try to return the pile to an upright position. Grooming lowered the Gmax values of the infill systems by an average of over 20 Gmax as measured using the CIST (Table 3).

After simulated traffic is re-imposed the Gmax of the groomed surfaces would be expected to increase. The duration of the reduction in Gmax due to grooming was not measured in 2003 but will be monitored in 2004 as simulated traffic is resumed.

Traction

One of the primary concerns with any playing surface is the effect the surface has on lower extremity injuries to athletes. An athlete makes numerous and complicated movements on a playing surface that are affected by the cleated shoe - surface interface. Some of these movements have been categorized into translational, rotational, static, and dynamic traction (Valiant, 1989). High traction characteristics of a cleated shoe have been shown to enhance an athlete's abilities to run fast and make rapid changes in running direction. Krahenbuhl (1974) and Morehouse and Morrison (1975) reported that athletes wearing cleated shoes could run through an agility course faster on a traditional synthetic turf surface compared to a natural turfgrass surface. The results of these studies imply that increased traction between a cleated player and the surface enhances an athlete's performance.

In some conditions, low traction is desirable. Excessively high friction of tennis surfaces may be related to increased injuries (Nigg and Yeadon, 1987). With respect to excessive traction, however, excessive frictional resistance to rotation has received the greatest attention. Foot fixation, or the inability of the foot to rotate freely against the surface, has been implicated in the etiology of knee injuries (Cameron and Davis, 1973; Skovron et al. 1990). Increased resistance to rotation of certain cleated shoes designed for American football has been associated with an increase in the number and severity of knee injuries (Lambson et al. 1999; Torg et al. 1974).

In the Penn State infill synthetic turf study, traction is being measured using a modified Pennfoot device (McNitt et al. 1997). Pennfoot was modified, prior to the start of the Penn State study, so that is would meet the requirements of the proposed ASTM Work Number 486 standard method for measuring the traction between a cleated shoe and a playing surface (American Society of Testing and Materials, 2004). The pressure applied to the piston that moves the shoe across the surface is now created with a motorized hydraulic pump and monitored with a pressure transducer connected to a computer. The rate of travel is approximately 0.5 m s^{-1} and 90° s^{-1} for linear and rotational traction measurements, respectively. The loading weight used was 126 kg and the shoe was in a forefoot only stance.

Table 4. Translational and rotational traction determined by proposed ASTM traction standard (Work number 486) and a 126 kg normal force prior to and after grooming[1].

	Translational Traction (μ^1)		Rotational Traction (Nm)	
Treatment	Pre-grooming	Post-grooming	Pre-grooming	Post-grooming
Astroplay	1.30	1.47	68.9	67.1
Astroturf	1.52	1.60	69.1	68.8
Fieldturf	1.35	1.58	68.0	66.5
Nexturf	1.38	1.50	70.3	67.1
Omnigrass 41	1.45	1.55	66.7	65.4
Omnigrass 51	1.40	1.56	67.6	67.2
Sofsport	1.36	1.44	68.7	67.9
Sprintturf	1.25	1.38	66.2	66.6
LSD (p=0.05)	0.14	0.11	6.6	2.9

[1] Traction coefficient (μ) is the horizontal traction force divided by the normal force (loading weight)

A limited portion of the traction results are shown in Table 4. The results indicate that the infill synthetic turf systems tended to have lower translational traction values when compared to traditional synthetic turf (Astroturf). Fewer differences were apparent when rotational traction was measured. Grooming increased translational traction but had little effect on rotational traction. These preliminary year one results indicate that grooming may increase player performance without a corresponding increase in lower extremity injuries (Shorten et al. 2003). Future research at Penn State will examine the effect of temperature, moisture, and shoe type on both rotational and translational traction of athletes of varying weight.

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