RECREATIONAL SURFACES

Recreational surfaces are synthetic, durable areas of consistent properties designed for various activities, including the high performance requirements of baseball, cricket, field hockey, football, golf, jumping, soccer, tennis, track, wrestling, and others. The category also includes indoor–outdoor carpets and similar materials designed for low maintenance in home or light recreational service. The characteristics of the artificial playing surface may be selected to match natural surfaces under ideal conditions or may have special features for specific sports purposes. In all cases, the intent is to provide appropriate functionality for the activity combined with good durability of the product. In most cases, the artificial surface permits greatly increased utilization compared with natural grass.

A grass-like artificial surface was installed for the first time in 1964, at Moses Brown School (Providence, Rhode Island) (1). In 1966, artificial turf was installed in the Houston Astrodome in Texas. These surfaces consisted of green pigmented, nylon-6,6 pile ribbon, with a cross-section resembling that of natural grass. Since that period, other fabrics of various pile ribbon and constructions have continued to become available commercially for indoor and outdoor facilities.

Resilient surfacing compositions for recreational use were introduced in tennis courts in the early 1950s. This led to the first all-weather, resilient athletic track installation at the University of Florida (Gainesville) in 1958, using a composition similar to that of tennis courts. The polyurethane running track used in the Olympic games at Mexico City in 1968 started a new era in this highly competitive sport. The uniformity and resilience of the synthetic track contributed to new speed records, and such tracks soon became standard throughout the world. In addition to the performance properties, the all-weather aspects of a synthetic track offered advantages for scheduled events and practice. The original system contained a rubber- and clay-filled polyurethane with polyurethane chips embedded in the surface. A wide variety of systems followed, including polyurethane with vinyl or rubber chips or sand finish for an all-weather skidproof surface, so-called sandwich tracks consisting of a bound rubber base with a polyurethane surface, bound rubber chips alone with a painted surface, and many others. A similar, smooth surface product was used for basketball. For tennis, a sand finish proved acceptable, but the polyurethanes were not competitive in cost with coated asphalt(qv) and molded vinyls and polyolefins.

Other more recent examples of recreational surfaces or components are artificial turf variations for golf tee mats and croquet, permanent resilient base layers replacing asphalt or asphalt and shock-absorbing underpad in artificial turf field installations, and sand-filled turf.

These grass-like and resilient installations require substantial amounts of synthetic materials. A typical sports field covered with artificial turf requires approximately 15,000 kg of fabric, 15,000–30,000 kg of shock-absorbing underpad, and 5,000–10,000 kg of adhesive and seaming materials. The artificial surface for a 0.40-km running track may require 50,000–70,000 kg of materials. Paint striping and marking of turf, tracks, and courts call for additional materials.

1. Types of Surfaces

Recreational surfaces must provide certain performance characteristics with acceptable costs, lifetimes, and appearance. Arbitrary but useful distinctions may be made for classification purposes, depending on the principal function: a covering intended primarily to provide an attractive surface for private leisure activities, eg, patio surfaces; a surface designed for service in a specific sport, eg, track surfaces; or a grass-like surface designed for a broad range of heavy-duty recreational activities, including professional athletics, eg, artificial turf for outdoor sports.

1.1. Light-Duty Recreational Surfaces

Artificial surfaces intended for incidental recreational use, eg, swimming pool decks, patios, and landscaping, are designed primarily to provide a practical, durable, and attractive surface. Minimum cost is a prime consideration and has driven the quality of some such products to a low level. Most surfaces in this category utilize polypropylene ribbon and a tufted fabric construction (see Olefin polymers, polypropylene).

1.2. Single-Use Athletic Surfaces

Included here are running tracks, tennis courts, golf tee mats, putting greens, and other installations designed for a particular sport or recreational use. Specific performance criteria are important and differ depending on the application. In the case of a tennis surface, for example, friction and resilience characteristics are critical because they affect footing and the behavior of the tennis ball. Another special application is a warning area or track adjacent to a sports surface, eg, the area between the fence and the playing portion of a baseball field. This frequently is covered with a special surface which must feel different from the main area to warn the player approaching the fence.

1.3. Multipurpose Recreational Surfaces

The performance demands control the design for artificial surfaces in this category, which include, for example, the playing surface for American football and soccer. The shock absorbency of the system affects player safety and long-term performance under very heavy, usually multipurpose use. The grass-like fabrics used for these applications are made from various pile materials, including polypropylene, nylon-6,6, nylon-6, and polyester (see Fibers, olefin; Fibers, polyester; Polyamides). The fabric may be woven, knitted, or tufted. The underpad is derived from various materials, representing a compromise of properties. Because of the importance of safety and performance, fabric and installation costs are higher than those for the lighter duty surfaces.

2. Performance Characteristics

2.1. User-Related Properties

The most important element in the player's contact with the surface is traction. Shoe traction for light-duty consumer purposes need address only provision of reasonable footing. The frictional characteristics are obviously of much greater importance in surfaces designed for athletic use. For specialized surfaces such as a track, shoe traction is especially critical. With grass-like surfaces, traction is significantly affected by pile density and height, and other aspects of fabric construction.

The coefficient of static friction between the playing surface and the shoe determines traction. To test traction for grass-like surfaces, the force required to initiate movement in a weighted sports shoe resting on the artificial turf is measured (2). The coefficient of static friction is defined as the force pull in a direction parallel

Table 1. Traction Characteristics of Surfaces[a]

Surface	Static friction coefficient[b] Dry	Wet	Directionality index[c]
	Recreational surface		
tufted polypropylene	1.7–2.0	1.8–2.1	0.1–0.2
nylon-6,6			
knitted	1.8–2.0	1.6–1.8	0.10–0.25
tufted	1.9–2.1		0.05–0.15
woven	1.9–2.1		0.05–0.15
natural grass[d]	1.0–2.2	0.7–1.4	
	Indoor–outdoor carpeting		
tufted polypropylene	0.4–1.5	0.4–1.5	

[a]Ranges measured with appropriate sports shoes for the indicated surfaces.
[b]Defined as the average value measured in the four principal directions parallel to the fabric surface: two across the pile, one with, and one against the pile.
[c]Defubed as the average absolute deviation of the four traction values from the mean.
[d]The range is determined by the type and condition of grass.

Table 2. Effect of Fabric Construction on Traction Characteristics

Fabric[a]	Description	Static friction coefficient[b]	Directionality index[b]
standard	height at 1.27 cm	1.8–2.0	0.2
	increased curl[c]	1.8–2.0	0.15
	texturized[d]	1.8–2.2	0.02–0.05
high	height at 1.02 cm	1.8–2.2	0.15

[a]55.5 tex (500den) nylon-6,6 pile ribbon.
[b]See Table 1 for definitions.
[c]Curl is an index of filament modification imparted to the ribbon during processing.
[d]Refers to a fiber-modification process.

to the playing surface, divided by vertical force loading. An alternative method is simply to place the weighted shoe on an inclined plane of the surface of interest, and to determine the angle, θ, at which slippage is initiated. Because of resolution of the gravity forces involved, coefficient of friction is tan θ. By either method, vertical force loading must be sufficient to approximate actual penetration. The shoe characteristics significantly affect the traction.

Typical static friction coefficients are given in Table 1. These data demonstrate that the absolute traction values for synthetic surfaces are satisfactory in comparison with natural turf, provided that shoes with the appropriate surfaces are employed. Synthetic surfaces by virtue of their construction are to a degree directional, a characteristic which, when substantial, can significantly affect both player performance and ball roll. This effect is evident in a measurement of shoe traction in various directions with respect to the turf–pile angle. Some traction characteristics are directly affected by the materials. For example, nylon pile fabrics, exhibiting higher moisture regain, have different traction characteristics under wet and dry conditions than do polypropylene-based materials. Effects of artificial turf fabric construction on shoe traction are given in Table 2. Especially effective in aiding fabric surface uniformity is texturing of the pile ribbon, a process available for the two principal pile materials: nylon and polypropylene.

Abrasiveness of an artificial turf surface upon contact with bare skin is a performance criterion to be considered. Artificial surfaces are more abrasive than natural grass in good condition, although the latter typically contains much higher levels of bacteria (3). A suitable laboratory method for comparing abrasiveness among artificial turfs is to use the turf as the abrader on a Schiefer fabric tester (ASTM D1175) and determine the weight loss per cycle when applied to a stiff, friable foam or the like (4).

In general, user-related properties should encompass a good balance of traction, comfort, and safety. The right combination of energy recovery and shock absorption enables the athlete to perform at maximum potential in relative comfort. For running tracks, resilience minimizes energy dissipation on the surface. A particular range is optimal for the track modulus of elasticity (5). All of these considerations are dependent on the footgear selected. Spikes on running shoes should be long enough to provide adequate traction with easy separation. Ideally, dull spikes afford traction by depression of the surface and gain additional energy for the runner, because the resilient surface rebounds when the weight is lifted. With turf, a specific shoe design for the surface is important.

2.2. Game-Related Properties

For some activities, such as running and wrestling, the only consideration is the direct impact by the player. For others, eg, tennis, baseball, or soccer, the system must also provide acceptable ball-to-surface contact properties. Important ball-response properties on the artificial surface are coefficients of restitution and friction, because these directly determine the angle, speed, and spin of the ball.

The coefficient of restitution is defined as the ratio of the vertical components of the impact and rebound velocities resulting when a ball is dropped or thrown onto a playing surface. The velocities or related rebound heights may be measured photographically. Criteria such as ball inflation pressure, air temperature, and other details must be specified.

The coefficients of static friction between a ball and the playing surface are the ratios of the horizontal forces necessary to initiate a sliding or rolling motion across the surface to the normal forces (wt) perpendicular to the surface. The sliding and rolling coefficients of dynamic friction are similarly defined in terms of the forces necessary to sustain uniform motion across the playing surface. These friction coefficients determine slip or retention of inertial effects present upon impact. In golf, for example, the driven ball may bounce forward after the first impact with the surface, and bounce backward after the second. In this particular example, the combination of velocities and friction creates a slipping condition on the first bounce; on the second, the rotational backspin imparted to the ball when first hit is activated by sufficiently large friction. In soccer, on the other hand, the ball in play rarely slips because a coefficient of friction ≥ 0.4, which is almost always achieved, is sufficient to transfer momentum.

Values for ball-response parameters in various sports are given in Table 3 (6). Artificial surfaces can be designed to match certain desirable game-response parameters of natural grass surfaces and provide these properties consistently. Also, response is confined to a narrower range and is less affected by weather. As a general rule, artificial turf surfaces tend to be somewhat livelier in ball response, velocity, and distance of roll, with coefficients of friction lower than those for natural grass.

A more recent artificial turf product designed for a specific use is the golf driving mat, used for practice drives with conventional tees at commercial driving ranges. These products must be designed to withstand the considerable forces imparted to the surface by the golf club and the twisting motion of the golfer's heel. An additional accommodation is a means for inserting tees into the mat.

2.3. Impact Properties

Artificial playing surfaces for moderate to heavy use must provide shock absorbency for player comfort and safety. This is achieved by incorporation of a resilient layer, usually a shock-absorbing underpad.

An ideal shock-absorbing medium, eg, for football in the United States, would combine a reasonable softness in normal shoe contact with a high capacity for dissipation or distribution of kinetic energy involved in the impact of a player's fall. Various foamed elastomers are suitable for this purpose (see Elastomers,

Table 3. Physical Parameters[a] for Ball Response from Sports Surfaces

Sports surface	Coefficient of restitution	Friction coefficients		
		Static	Sliding	Rolling[b]
soccer				
nylon turf-pad	0.7	0.4	0.3–0.4	
polyester turf-pad	0.7	0.4	0.3–0.4	
polypropylene turf-pad	0.7	0.5	0.5	
baseball				
nylon turf-pad	0.6	0.5–0.6	0.6	0.1–0.2
natural grass	0.5	1.0	0.8	0.2
golf				
nylon turf-pad	0.5	0.3–0.5		0.1–0.2
natural grass	0.4	0.5		0.1–0.2
tennis				
nylon turf-pad	0.7	0.4–0.6		0.1–0.2
natural grass	0.8	0.7		0.1–0.2

[a]Approximate values.
[b]Rolling resistance increases markedly with rolling velocity.

synthetic). The design criterion is the ability to dissipate energy of motion by reducing impact deceleration through hysteresis losses in the material. A useful device for characterizing the required properties is a dynamic mechanical impact tester (ASTM F355). It employs an instrumented missile that is allowed to fall freely from a specific height onto the surface. Sensing components record electronically the force- and displacement-time profiles of the missile throughout the interval of first penetration and rebound from the playing surface. The plots shown in Figure 1 illustrate the acceleration and displacement between initial and final contact of the missile with the playing surface, both vs time. The deceleration forces increase as the missile penetrates the surface, reach a maximum, and decrease as the missile rebounds from the surface. The effectiveness of the shock-absorbing medium is indicated by the height of the maximum or, more accurately, the integrated profile throughout the duration of impact, calculated according to the severity index, $\oint g^{5/2}dt$, where g = acceleration acceleration expressed in multiples of that due to gravity and dt is the time differential (7). The more effective the shock-absorbing material, the less sharply peaked the $g_{\max}$ curve and the broader and shallower the $g_{\max}$ profile. Effective performance would be achieved by a material displaying large hysteresis in which the impact of the falling weight is progressively absorbed without rebound. Clearly, because a useful system must also be reversible, this extreme example is not practical. Useful materials for shock absorbency have the ability to dissipate gradually the impact of the falling object, with a substantial conversion of the total kinetic energy to heat through hysteresis losses.

These shock-absorbing characteristics of underpad materials or resilient surfaces are functions of material selection, physical composition, thickness, and temperature. The sensitivity of performance to physical characteristics of the shock-absorbing medium is illustrated in Table 4 and Figure 2. Clearly, thicker materials offer better shock absorbency. However, in practice an excessively thick underpad may result in unsure footing as well as increased cost. Thermal effects must be considered because use temperatures can easily range from below freezing to 65°C in the sun. The ideal system would provide a relatively flat $g_{\max}$ response over this range. A compromise is a design for $g_{\max}$ peaks up to about 250 and a severity index below 1000 within a reasonable range of temperatures.

By way of comparison, $g^{\max}$ for natural grass playing fields in late autumn ranges from about 75 for wet fields to 280 for frozen turf (8). The intermediate values observed depend on soil type, moisture, condition, and other variables.

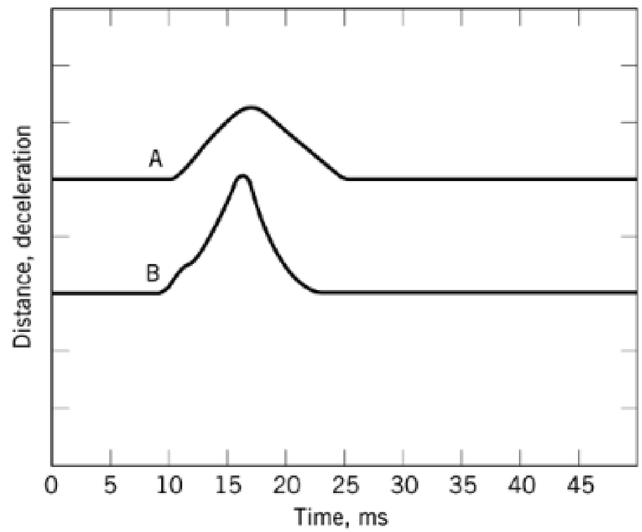

Fig. 1. Deceleration and penetration curves from dynamic impact tester. Time vs distance penetrated (A) and deceleration (B). Distance between vertical ticks for A=12.7 mm; for B=50 g.

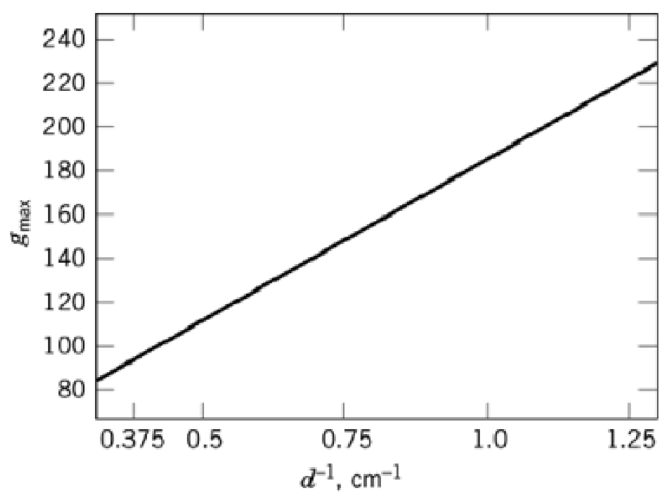

Fig. 2. Shock absorption g_{max} vs thickness d for typical polyurethane resilient surface, measured according to Procedure B of ASTM F355, using a 6.8-kg hemispherical missile dropped from a height of 30 cm.

2.4. Durability

Grass-like surfaces intended for heavy-duty athletic use should have a service life of at least eight years, a common warranty period provided by suppliers. Lifetime is more or less proportional to the ultraviolet (uv) exposure (sunlight) and to the amount of face ribbon available for wear, but pile density and height also have an effect. Color is a factor; generally uv absorption is highest with red fabrics and least with blue. In addition, different materials respond differently to abrasive wear. These effects cannot be measured except in simulated field use and controlled laboratory experiments, which do not necessarily reflect field conditions.

Table 4. Properties of Typical Underpad Materials

Property	Foam, % closed cells		Poured elastomer
	75–85	90–95	
thickness, cm	1.6	1.6	1.0
tensile strength, kPa[a]	620	655	2700
density, kg/m^3	96	256	1300–1400
g_{max}[b] at °C			
21	85	125	105[c]
−12	105	150	
49	120	150	

[a]To convert kPa to psi, multiply by 0.145.
[b]61-cm (2 ft) drop height of 9-kg (20 lb) flathead missile (ASTM F355), unless otherwise noted.
[c]22.8-cm (9 in.) drop height of hemispherical body.

Table 5. Abrasion Tests for Artificial Turf, Effective Pile Loss, %

Surface	Fiber size, tex[a]	Taber method[b]	Schiefer method[c]
tufted polypropylene	844	5	7
knitted nylon-6,6	55.6	21	0.2
knitted polypropylene	33.3		2.7

[a]To convert tex to den, divide by 0.1111.
[b]ASTM D1175, Rotary Platform, Double Head Method (5000 cycles).
[c]ASTM D1175, Uniform Abrasion Method (5000 cycles).

An instrument commonly in use for providing uv exposures, with intermittent condensation cycles, is the QUV Accelerated Weathering Tester (Q-Panel Company, Cleveland, Ohio). The grass-like ribbons on fabrics exposed may be monitored periodically for changes in physical properties. The Taber and Schiefer abrasion tests (ASTM D1175) evaluate fabrics and fabric constructions for potential wear properties. However, as the conflicting data in Table 5 indicate, any specific accelerated wear test to predict longevity of fabrics is suspect, unless the tests are applied to closely related fabrics for which actual wear-use data are available. Schiefer evaluation, performed periodically on grass-like fabrics exposed to outdoor weathering, is a useful accelerated wear test.

Other tests provide indexes to grab strength (ASTM D1682), tensile strength, and surface durability, including tuft bind (ASTM D1335), in which the force required to dislodge a surface element from its backing is measured. These and other tests (9) are indicators of physical endurance, as can best be simulated in the laboratory.

Artificial surfaces must be resistant to cigarette burns, vandalism, and other harm. Fire resistance is most critically evaluated by the NBS flooring radiant panel test (10). In this test, a gas-fired panel maintains a heat flux, impinging on the sample to be tested, between 1.1 W/cm^2 at one end and 0.1 W/cm^2 at the other. The result of the burn is reported as the flux needed to sustain flame propagation in the sample. Higher values denote greater resistance to burning; results depend on material and surface construction. Polypropylene turf materials are characterized by critical radiant flux indexes which are considerably lower than those for nylon and acrylic polymers (qv) (11).

Table 6. Typical Properties of Yarns Suitable for Pile Components of Artificial Surfaces

Property	Polypropylene	Poly(ethylene terephthalate)	Nylon-6,6
density, g/cm^3	0.91	1.38	1.14
melting point, °C	170	250	265
tenacity, N/tex[a]	0.22	0.18–0.35	0.31
elongation, %	25	30–100	33
moisture regain[b] at 21°C and 65% rh, %	0.1	0.4	4

[a]To convert N/tex to g/den, multiply by 11.33.
[b]Equilibrium moisture or water content.

3. Materials and Components

A grass-like recreational surface system includes the top material directly available for use and observation, backing materials that serve to hold together or reinforce the system, fabric-backing finish, a shock-absorbing underpad system if any, and adhesives (qv) or other joining materials. The system is installed over a subbase, usually of asphalt or concrete.

3.1. Surface Materials

Pile materials used in grass-like surfaces may be selected from fiber-forming synthetic polymers, such as polyolefins, polyamides, polyesters, polyacrylates, vinyl polymers, and many others (see Fibers, elastomeric). These polymers exhibit good mechanical strength in the necessary direction. The materials shown in Table 6 are thermoplastic polymers that may be suitably pigmented before or during extrusion. Utilization of uv and heat stabilization (qv) is essential for outdoor use. An artificial turf of greater pile height and lower pile density is a suitable component of sand-filled turf fields.

3.2. Backing Materials

Any fiber-forming polymer with reasonable tenacity may be used in backing materials, including polyamides, polyesters, and polypropylenes. The backing provides strength and offers a medium to which the pile fibers can be attached. It is usually not visible in the finished product, nor does its presence contribute much to the characteristics of the playing surface. However, it provides dimensional stability and prolongs service life. Some properties of fabric backing materials may be inferred from the data in Table 6; however, more highly drawn fiber equivalents of greater strength are employed for backing applications.

3.3. Backing Finish

The backing material must be consolidated with the pile ribbon. In tufting, for example, the tufts are locked to the backing medium by the primary finish. In weaving and knitting, the finish seals and stabilizes the product. Backing materials are usually applied as a coating which is subsequently heat-cured. For tufting, preferred choices are poly(vinyl acetate), poly(vinyl chloride), polyurethane resins, and latex formulations. For knitted fabrics, poly(vinylidene chloride), acrylics, or polystyrene–rubber latices are used.

3.4. Underpads

Shock-absorbing underpad material is usually made of foamed elastomer, which provides good energy absorption at reasonable cost (see Foamed plastics). The foamed materials may be poly(vinyl chloride), polyethylene,

Table 7. Properties of Poured-in-Place Polyurethane Resilient Surfaces

Property	ASTM test method	Desired range	Typical values[a]		
			A	B	C
impact resilience, %	D2632	30–50	42	49	36
hardness, Shore A-2	D2240	45–65	60	48	50
breaking strength, kPa[b]	D412	>2, 800	4,800	2,700	3,400
elongation to break, %	D412	100–300	210	298	168
tear strength, N/m[c]	D624	>11, 000	17,200	15,200	11,200
10% compression, kPa[b]	D575	590–860	720	500	520
compression recovery, %	D395 (A)	>95	100	99.6	98.7

[a]Of laboratory samples prepared identically from different raw materials.
[b]To convert kPa to psi, multiply by 0.145.
[c]To convert N/m to lbf/in. (ppi) sample thickness, divide by 175.1.

polyurethanes, or combinations of these and other materials. A newer material of interest is made from ground rubber particles, bonded with a polyurethane. Typical foam densities may range from 32 to 320 kg/m^3. Important criteria include tensile strength, elongation, open-cell vs closed-cell construction, availability in continuous lengths, softness in energy-absorbing properties, resistance to chemicals, water absorption, compression-set resistance, and cost. Resistance to water absorption is very important, especially if the system is subjected to below-freezing temperatures. Closed-cell materials are most resistant to moisture.

Some recreational surfaces, in particular the lighter weight materials for patios and similar applications, are installed without shock-absorbing underpads. A light coating is usually joined directly to the turf during manufacture, providing a certain degree of softness and grip adequate for the service intended.

3.5. Coating, Adhesives, and Joining Materials

Grass-like surfaces are employed over substantial areas, and lengths of rolls must be joined, glued, or sewn together. A variety of adhesives, ranging from low cost poly(vinyl acetate) materials to cross-linked epoxy cements, is utilized. Sewing threads may be selected from the group of drawn, high tenacity yarns such as nylon-6,6 and polyester.

The common asphalt tennis courts have been improved significantly by synthetic all-weather coatings with superior appearance and characteristics. Typical coatings are vinyl or acrylic compositions in various colors. Poured-in-place and preformed systems of polyurethane, vinyl, and rubber, although often used, are more expensive than coated asphalt or concrete. More recently, open molded mats that are easily installed as interlocking tiles have been used to construct new or to repair tennis courts. These mats are less expensive than the poured-in-place and preformed systems that require gluing. They are easily removed if necessary, and thus are easily and quickly repaired. In addition, the open structure allows rapid drainage after rain. Such molded systems are usually made of polyolefins, vinyls, or polyolefin–rubber blends, with pigmentation and stabilizers. Properties of materials, typically polyurethanes, used for the smooth recreational surfaces of running tracks and tennis courts are shown in Table 7.

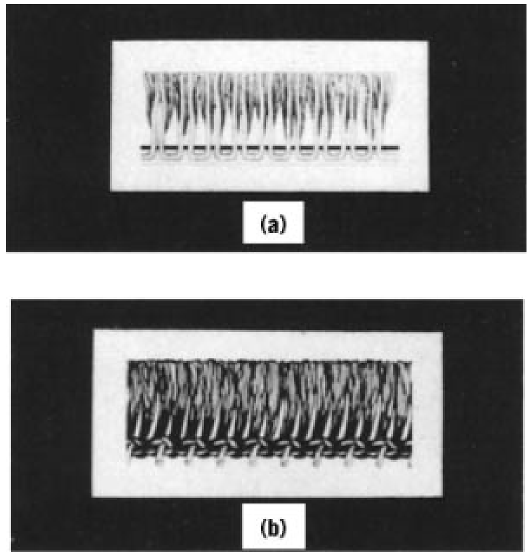

Fig. 3. Construction of (**a**) pile fiber held in place by latex (tufted) and (**b**) pile fiber tied into backing (knitted) grass-like artificial surfaces.

4. Fabrication of Grass-Like Surfaces

4.1. Tufting

The tufting process is frequently employed in the construction of grass-like surfaces (12). The manufacturing techniques are essentially those developed for the carpet industry with characteristics of high speed and economy. Pile yarn is inserted into the back side of a woven or nonwoven fabric constituting the primary backing by a series of needles, each creating a loop or tuft as the yarn penetrates the backing, and forms the desired pattern on the other side. For artificial surfaces, the looped tufts that form in this process are cut to provide the desired individual blades in the playing surface. Cutting elements incorporated in the tufting machine sever the loops automatically in the process of forming the pile.

Depending on the fabric width and desired pile density, a tufting machine may incorporate 1000–2000 needles, which simultaneously insert the tufts across the fabric width. The needles may operate at speeds above 500 strokes per minute, contributing to a highly efficient output of fabric yardage. The primary backing for tufted surfaces is usually a woven, synthetic filament fabric. After the tufts have been inserted, pile fiber and backing components are fused together by applying a backing finish and, optionally, a reinforcing secondary backing fabric (Fig. 3). In terms of total recreational surface production, tufting is by far the most utilized fabric construction method.

4.2. Knitting

The knitting process, as applied to manufacture of artificial turf and related products, provides a high strength, interlocked assembly of pile fibers and backing yarns (Fig. 3). Pile yarn, stitch yarn, and stuffer yarn are assembled in one operation. The pile and stitch yarns run in the machine or warp direction. The stuffer yarns interlock the rows (wales) formed by the pile and stitch yarns, knotting the system together in the width direction. Knitted fabrics typically possess high strength and high tuft bind.

A machine with approximately 1000 needles continuously produces a fabric 5-m wide. The assembly process is more complex, slower, and more expensive than tufting. The pile yarn and stitch yarn are inserted into the knitting needle, and the stuffer yarn is interlocked with the others through a separate feed mechanism of the machine. As with tufting, the loops of the pile fabric formed are slit, creating the desired individual blades.

The knitted fabric is subjected to a finishing operation in which a suitable backing material is applied to penetrate the yarn contact points and stabilize the structure. This process is usually accompanied by a heat treatment which stabilizes the fabric and conditions the pile.

4.3. Weaving

Weaving is a slower process than tufting or knitting. The process consists of a two- or three-dimensional meshing of warp, pile, and fill yarns that may be of different types. In contrast to knitted fabrics, yarns are not knotted together but interwoven at right angles. The pile yarns are cut by a series of wires that are continuously assembled into and withdrawn through the fabric loops. A suitable finish further stabilizes the fabric. The weaving technique is little used for recreational surfaces.

4.4. Finishing

In each of the processes discussed above, the artificial turf fabric is subjected to a finishing operation in which an adhesive, usually poly(styrene–butadiene), polyurethane, or poly(vinylidene chloride), is applied to the back side, with or without the optional reinforcing secondary backing, bonding the components and stabilizing the material. The finish may be applied with a knife or roll, in paste or foam form, followed by a heating and drying stage. The temperatures of application affect the pile ribbon properties.

4.5. Underlayment

An installed artificial turf system may or may not include components between the fabric and the subbase. Such components are not required for light-duty applications, but are essential in attaining the shock-absorbing properties required by heavy-duty surfaces. The foam underpads for shock-absorbing systems are made by incorporating a chemical blowing agent into the foam latex or plastisol. Voids of controlled size and number are uniformly distributed throughout the foam material. Closed-cell foam structures resist water absorption and are preferred for outdoor use. The underpad may be produced in slab or continuous roll form, usually up to five feet (1.5 m) in width.

5. Installation

Grass-like surfaces for heavy-duty athletic use usually are glued to or laid over a subbase of asphalt or other permanent foundation material. The shock-absorbing underpad component is in contact with the subbase layer, and the turf component is placed on top of the underpad. Turf panels are fastened together by sewing or gluing, and the entire perimeter of the grass-like surface is securely anchored to the subbase.

Newer variations of the normal asphaltic subbase include a permeable version (4) which allows rainwater to trickle through holes punched into the underpad and to drain away through the asphaltic subbase to a pipe grid system under the base (Fig. 4).

Bonding of the underpad to the subbase can vary from full glue-down or strip gluing, to loose-laying. The latter technique, without glue-bonding to asphalt, is employed in a float-drain construction in which rainwater drains laterally from the field between the pad and the asphalt. Glue is also omitted at the subbase interface

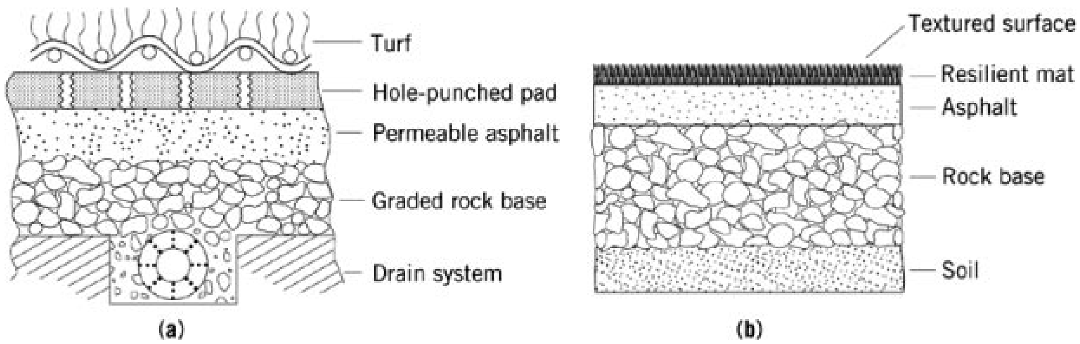

Fig. 4. Cross sections of (**a**) typical artificial turf and (**b**) resilient track surfaces.

in constructions where the pad is permanently bonded to fabric in the factory, and the composite is installed in the field. Loose-laying again is employed on convertible fields, such as indoor stadiums, where the turf can be removed to permit other sports uses of the subbase.

The Magic Carpet system (AstroTurf Industries) (13) is a novel installation technique in which turf and adherent underpad are unwound from a core and floated onto the subbase of a playing field by air pressure supplied from ducts in the base. To expose the subbase for other sports uses, the turf–pad combination is rolled up and stored at the edge of the field or in a recessed storage compartment.

For other recreational surfaces, such as running tracks, the installation techniques are quite different. Most are poured-in-place. An interlocking tile technique may be employed for tennis courts. In all cases, adequate provision for weathering and water drainage is essential. In general, the resilient surfaces are installed over a hard base (see Fig. 4) that contains the necessary curbs to provide the finished level. Outdoors, asphalt is the most common base, and indoors, concrete. A poured-in-place polyurethane surface (14) is mixed on-site and cast from at least two components, an isocyanate and a filled polyol of the polyether or polyester type. The latter has traditionally contained an organic mercury catalyst (15), which provides a system with selective reaction toward organic hydroxyl groups, reducing moisture sensitivity (see Urethane polymers); however, amine-type catalysts, eg, Dabco 33 LV, and other nonmercury catalysts are finding increasing environmental acceptance. The isocyanate is of the polymeric type, a toluene diisocyanate of methylenebis(phenyl isocyanate)-based prepolymer. Similar systems are used as binders for scrap rubber granules. The surface properties can be varied by the type and amount of fillers and the size of the rubber granules.

The mixed liquid is pumped into the area, where it cures and forms a slab. It may be poured in two layers to eliminate imperfections in the base. The first layer may be a preformed rubber slab which is glued to the base, or a mixture of reground rubber and binders or rubber and polyurethane. A textured surface may be imparted to the second coat with sand or chips.

Outdoor running tracks, indoor basketball courts, field house surfaces, and stadium turf require line markings and decorations. These are painted on with two-component epoxy paints or water-based acrylic latex, depending on the permanence desired. In stadiums used for different sports the markings can be changed. Markings in different colors for different sports may be desired in community and school installations. Indoor paints are usually permanent and compatible with the surface, ie, they are flexible without cracking and accept finish and maintenance coatings. An innovation is use of knitted- or tufted-in (white) pile yarn to provide permanent line markings in grass-like surfaces. Numerals and emblems of white or other contrasting colors may be inlain on the green fabric.

Table 8. Manufacturers and Trade Names of Artificial Turf Surfaces for Multisport Use

Product	Description	Manufacturer	Country
AstroTurf[a]	knitted nylon-6,6 fabrics	Southwest Recreational Industries	U.S.
Edel Grass	knitted nylon-6,6 and tufted polypropylene fabrics	Edel Grass	Netherlands
Konygreen	knitted nylon-6 fabrics	Kolon Industries	S. Korea
Omniturf	tufted polypropylene sand-filled fabrics	Southwest Recreational Industries	U.S.
Playfield Turf	tufted polypropylene fabrics	Playfield Industries	U.S.
PolyPro	knitted monofilament polypropylene fabrics	Southwest Recreational Industries	U.S
Polytan	tufted polypropylene fabrics	various	Germany
Sportilux	tufted and knitted nylon and polypropylene fabrics	Desso/DLW AG	Netherlands/Germany
Stadia Turf	tufted polypropylene fabrics	Southwest Recreational Industries	U.S.
Supergrasse	tufted polypropylene fabrics	Balsam Pacific	Australia
Tartan Turf[b]	tufted nylon-6,6 fabrics	3M	U.S.
Toray Turf	knitted nylon fabrics	Mitsubishi	Japan

[a]A subsidiary of Monsanto Company prior to 1988.
[b]Discontinued in 1976, no fields extant; included for historical perspective.

Table 9. Manufacturers and Trade Names of Other Recreational Surfaces

Product	Description	Manufacturer[a]
AstroTurf	knitted nylon-6,6 for golf mats	AstroTurf/Southwest Industries
Iron Mat	woven polypropylene for golf mats	AGR[b]
Pro Turf	knitted nylon-6,6 for golf mats	Southwest Synthetic Turf
Turf King	knitted nylon-6,6 for golf mats	Wittek
UltiMat	woven polypropylene for golf mats	Easy Picker
Martin Surfaces	polyurethane surfaces for track	Martin
Mondo	polyurethane surfaces for track	Mondo[c]
Southwest Track Products	polyurethane surfaces for track	Southwest Recreational Industries
Deco Turf	acrylic latex surface for tennis	Koch Materials
Kramer Court	sand-filled tufted fabrics for tennis	Kramer Court
Laykold	acrylic latex surface for tennis	Advanced Polymer Technology
Nova Grass	sand-filled tufted fabrics for tennis	Nova Grass
OmniCourt	sand-filled tufted fabrics for tennis	Advanced Polymer Technology
Plexipave	acrylic latex surface for tennis	California Products

[a]Manufactured in the United States unless otherwise noted.
[b]A division of Mohawk Carpet.
[c]Manufactured in Italy.

6. Commercial Products

For the purpose of illustrating the recreational surface market, manufacturers and trade names of commercial products are provided in Tables 8 and9.

In terms of surface area covered, artificial turf is the dominant commercial product in the category of artificial surfaces described in this article. Light-duty surfaces are the largest representative, followed by tennis court and multipurpose recreational surfaces.

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Fibers, olefin; Polypropylene; Urethane polymers; Fibers, polyester; Fibers, polyamides