British Society for Strain Measurement
Test and Analysis of Materials Performance in Sports Engineering

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FRICTIONAL AND ABRASIVE PROPERTIES OF SIX UNFILLED SYNTHETIC HOCKEY PLAYING SURFACES

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Sports Training Village

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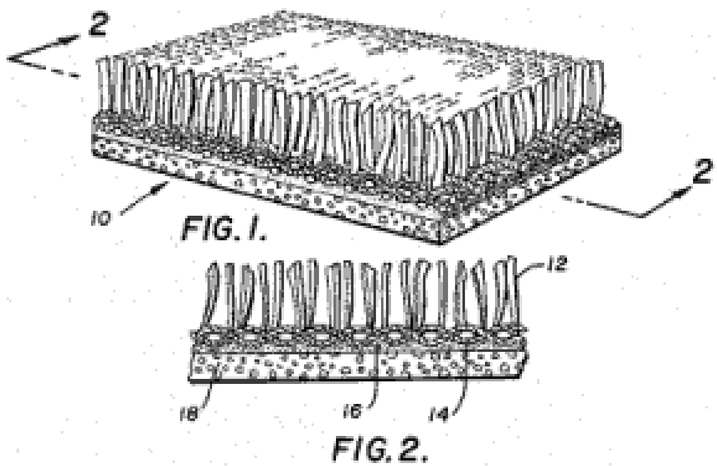
Artificial turfs

- Artificial hockey playing surfaces - 1976 Olympic Games in Montreal
- FIH – International Hockey Federation – specifies artificial turf
- More consistent playing surface improving ball control
- Original turfs were sand-based



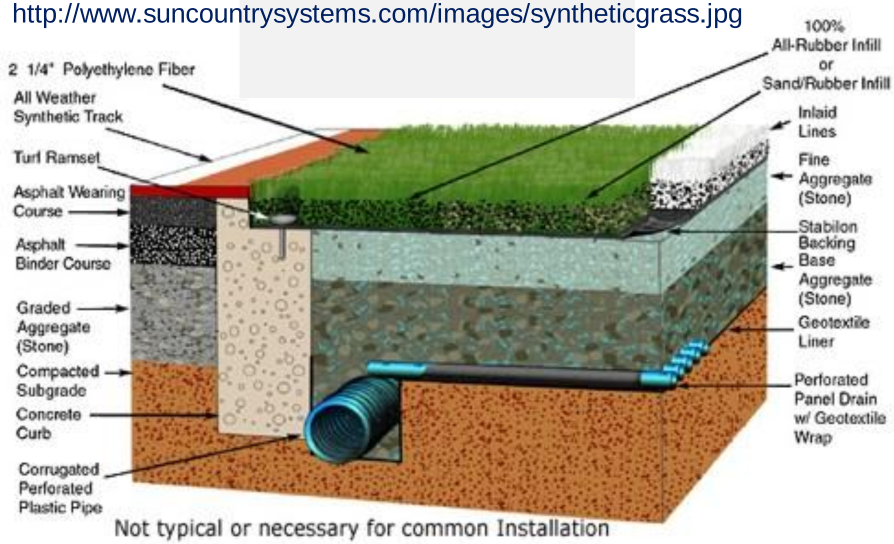
Astroturf
(U.S. patent #3332828)

Sand dressed turf
www.tenissurfaces.com

- Water-based turfs increase the pace and reduce abrasiveness

Advanced field base and drainage system

http://www.suncountrysystems.com/images/syntheticgrass.jpg



- **Turfs comprise polymer yarn (pile) in a polymer backing similar to domestic carpets**
- **Sand filling supports base of the pile but is abrasive - watered turfs reduce abrasiveness**
- **Watering before & during a match requires a drainage system**

www.englandhockey.co.uk

Player preferences

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- Fast game speed
- Low ball bounce
- Fairly hard but non-abrasive surface
- Enough grip underfoot for stability
- Consistent properties across the whole pitch
- Consistent water coverage in high winds
- Adequate drainage in heavy rain

Objectives of presentation

- To evaluate six artificial, unfilled turf samples of Global Standard with different yarn densities and pile heights

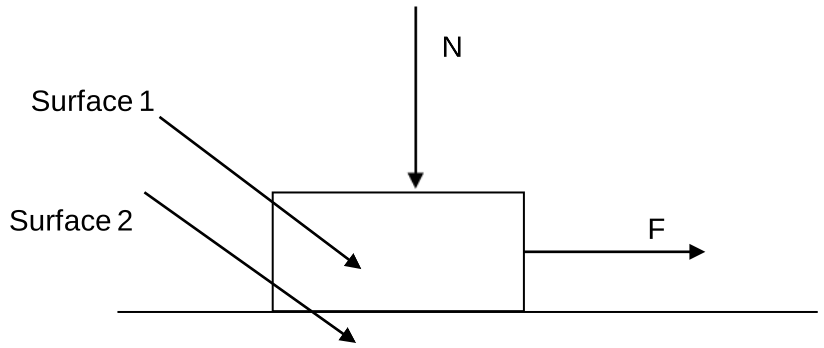
- To establish the static and dynamic coefficients of friction of the turfs in both dry and wet conditions, i.e. watered as specified by the FIH

- To conduct a unique test to assess the abrasiveness of the turf samples using a brittle foam friction pad

- To examine wear trails in the foam and characterise the surface roughness

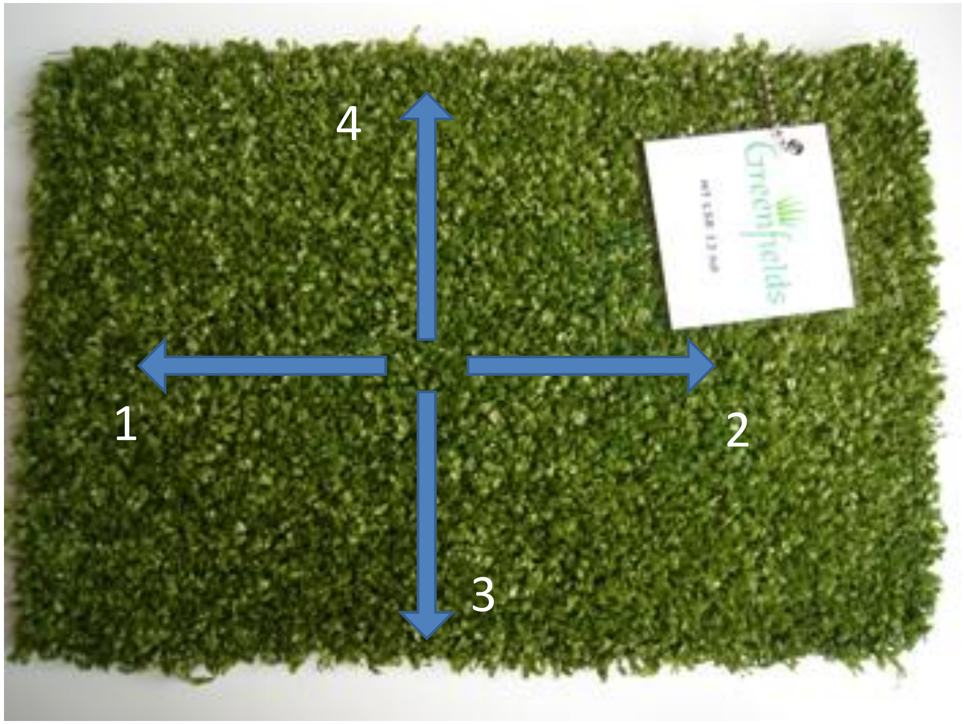
- To establish relationships between static and dynamic friction coefficients and surface roughness in dry and wet conditions

Coefficient of friction



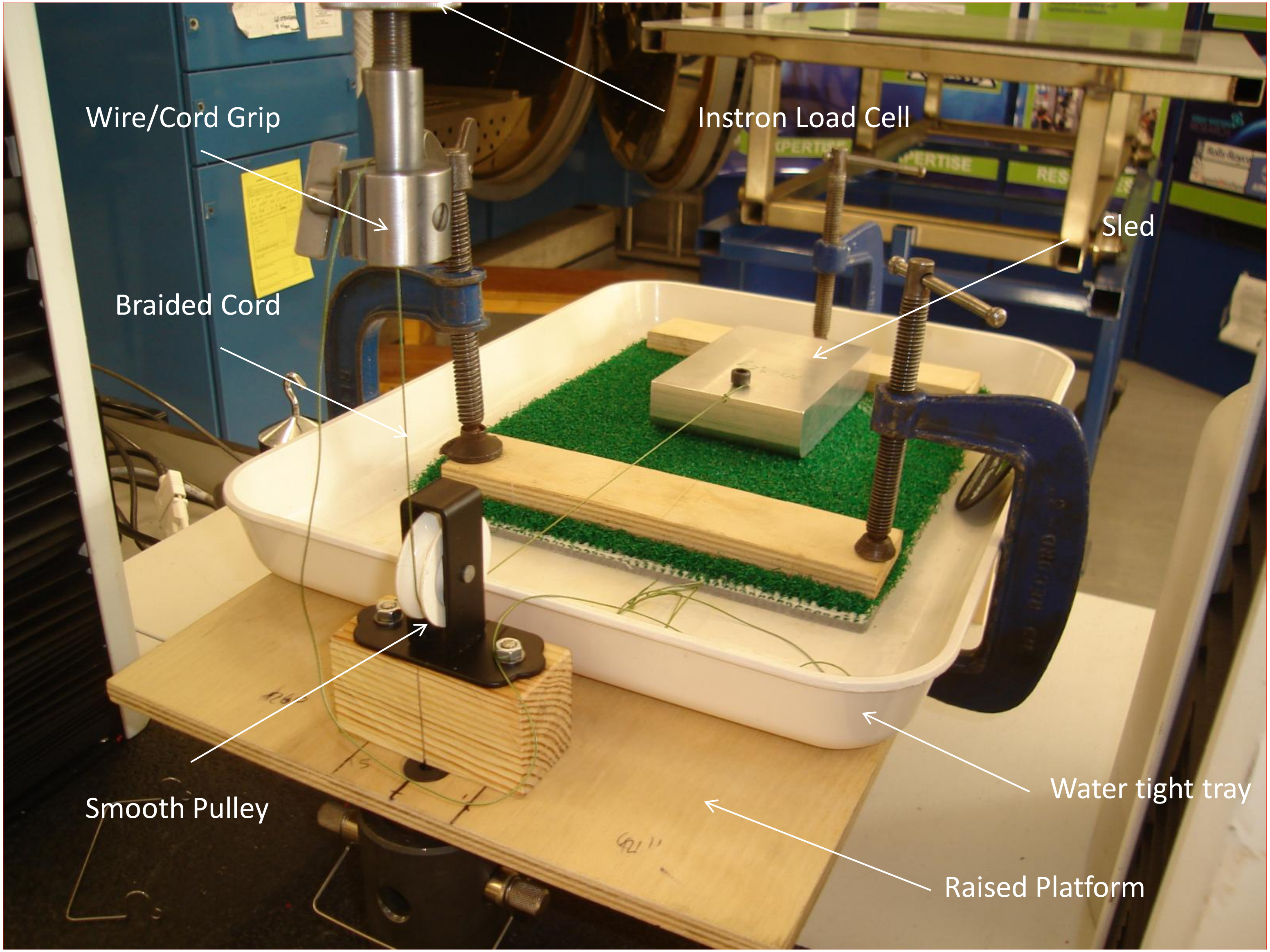
F = frictional force
μ = coefficient of friction
N = normal force

F = μN



- **Friction tests performed in four draw directions**
- **Turfs tested under wet and dry conditions**

Friction rig in Instron test machine



Weighted friction sled and clamping strips

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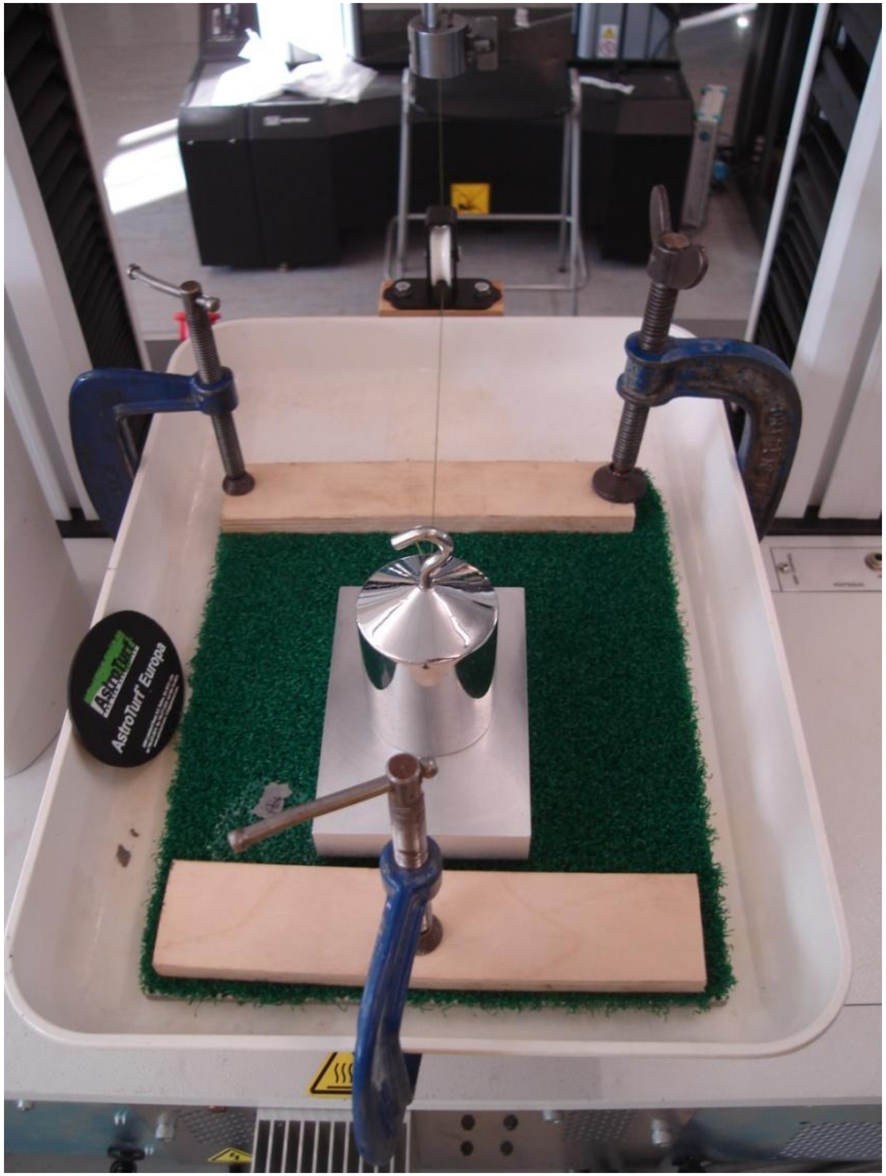
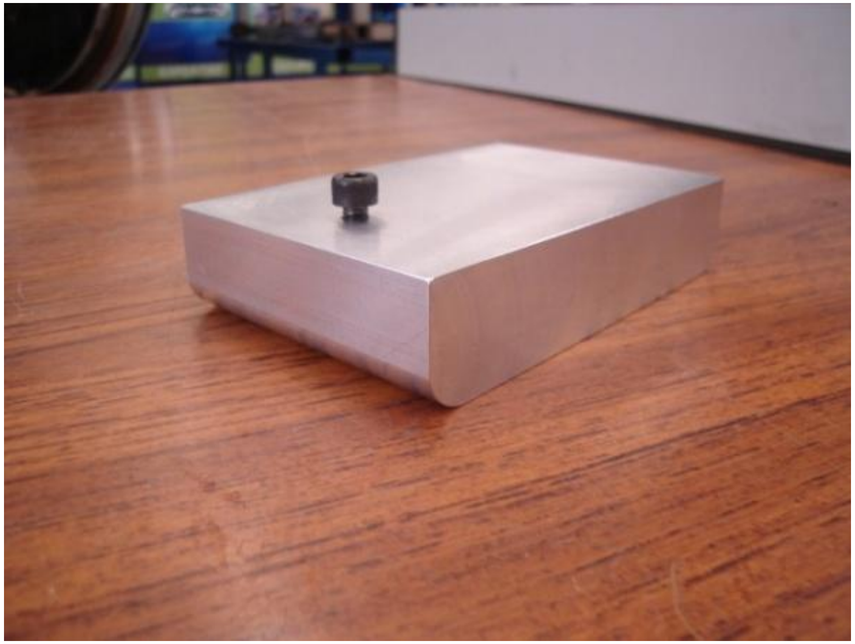
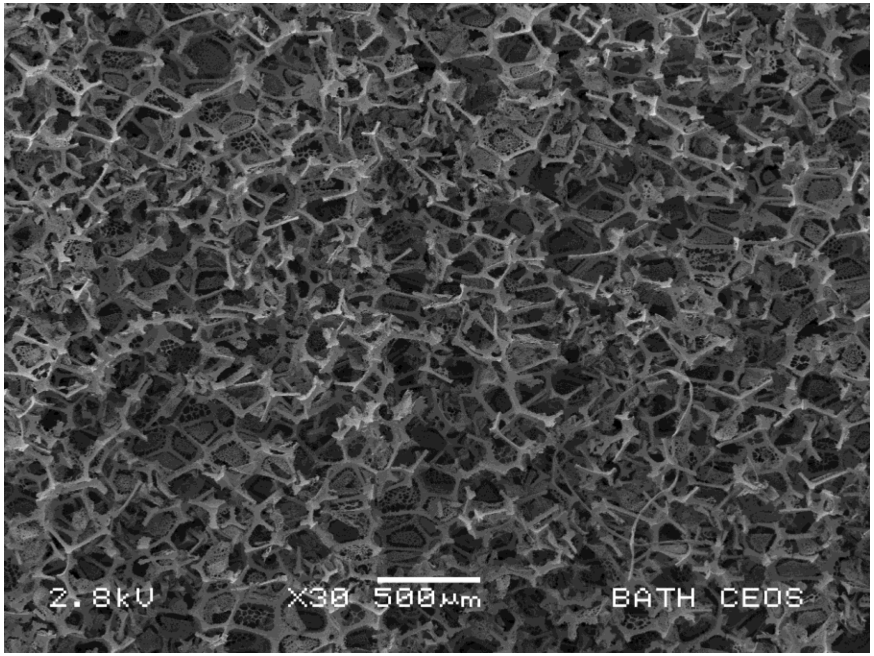
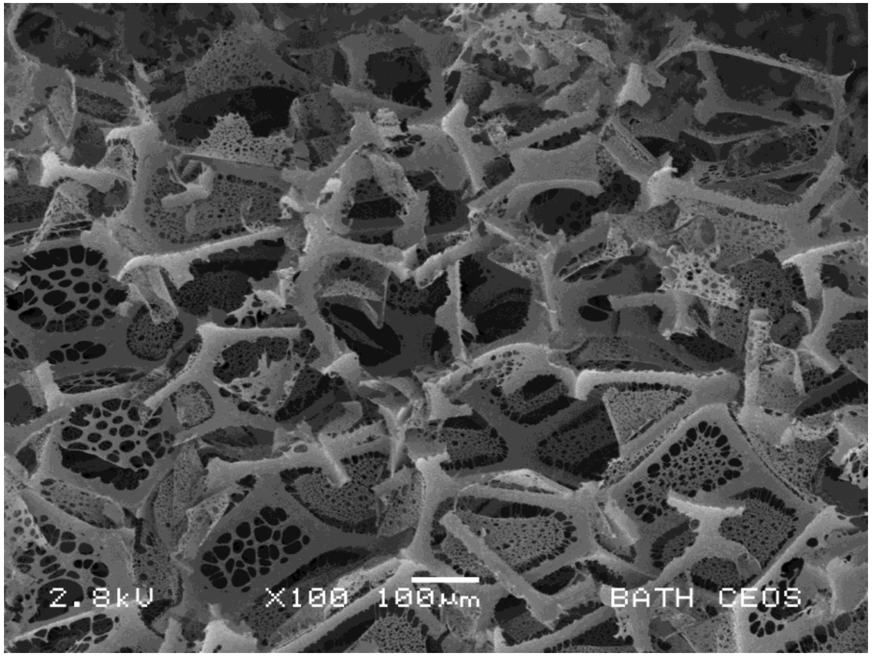




- Sled has radiused leading and trailing edges
- Sled plus bolt mass = 0.7 kg
- A 1 kg mass is added (equivalent to Securisport skin abrasion test)
- Compressive stress = 2.1 kPa
- Draw rate = 500 mm/min
- Draw distance ~60 mm
- Draw time ~ 7 s

OASIS® open cell floral foam for relative abrasion test





- **Oasis® open cell foam is highly friable**
- **Thin brittle strands fracture easily and uniformly**
- **Imprint of wear trails from sliding contact with the turf yarns are formed on the foam surface allowing surface roughness Ra to be measured**

OASIS® open cell floral foam attached to sled for relative abrasion test

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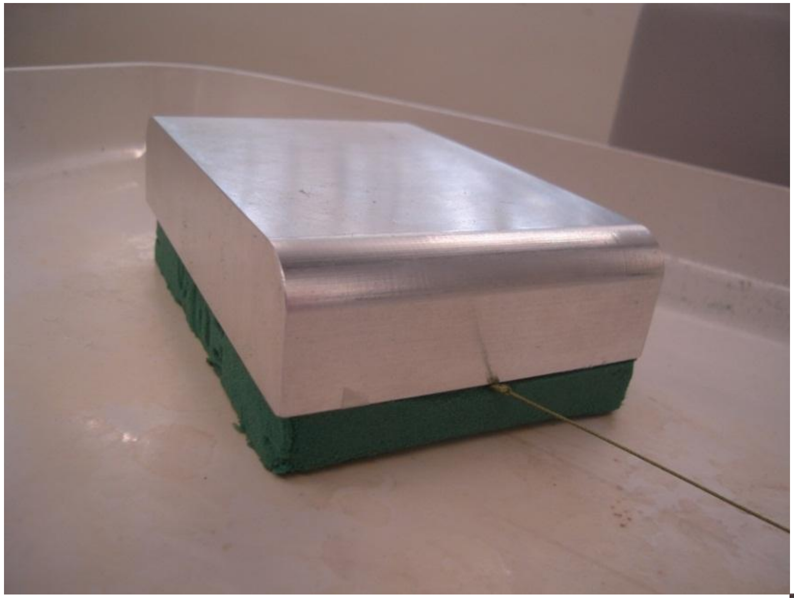

- Foam attached to sled with double-sided sticky tape
- Bolt head inverted
- Mass of sled and weight = 1.7 kg
- Foam block dimensions = 100x80x100 mm^3

- Foam drawn across surface of turf sample
- Foam is abraded and loses material
- Weight of foam measured before and after test
- Weight loss per metre calculated after 10 traverses of 60 mm
- Wet samples must be dried

Artificial turfs – low stiffness yarns

Sample 1: Nylon yarns, diamond cross-section, knitted into polyester primary backing bonded to 3mm polyurethane pad. Pile height 12mm and very dense.

Sample 2: Nylon 6, very fine diamond cross-section woven and bonded into thin polyurethane backing. Pile height 13mm and very dense.

Sample 3: Nylon yarns slightly finer and softer to the touch than Samples 1 & 2. Knitted directly into the backing. Pile height 10mm and very dense.

Samples 1, 2 & 3 all have thin yarns, inter-tangled with low stiffness.

Artificial turfs – high stiffness yarns

Sample 4: Polyethylene fibrillated yarns (~1.5mm wide) woven into backing material. Approx. 8 yarns organised in tufts, each tuft shredded to create a finer structure. Pile height is ~15mm and fairly dense.

Sample 5: Fibrillated polyethylene, slightly narrower tufts (~2mm wide) and slightly less dense than Sample 4. Tufts woven into polypropylene backing but left uncoated. Tufts contain ~12 yarns. Pile height 12mm.

Sample 6: Polyethylene monofilament ~1mm wide woven into polypropylene backing. Tufts contain ~10 yarns. Pile height 13mm.

Physical properties of synthetic turfs

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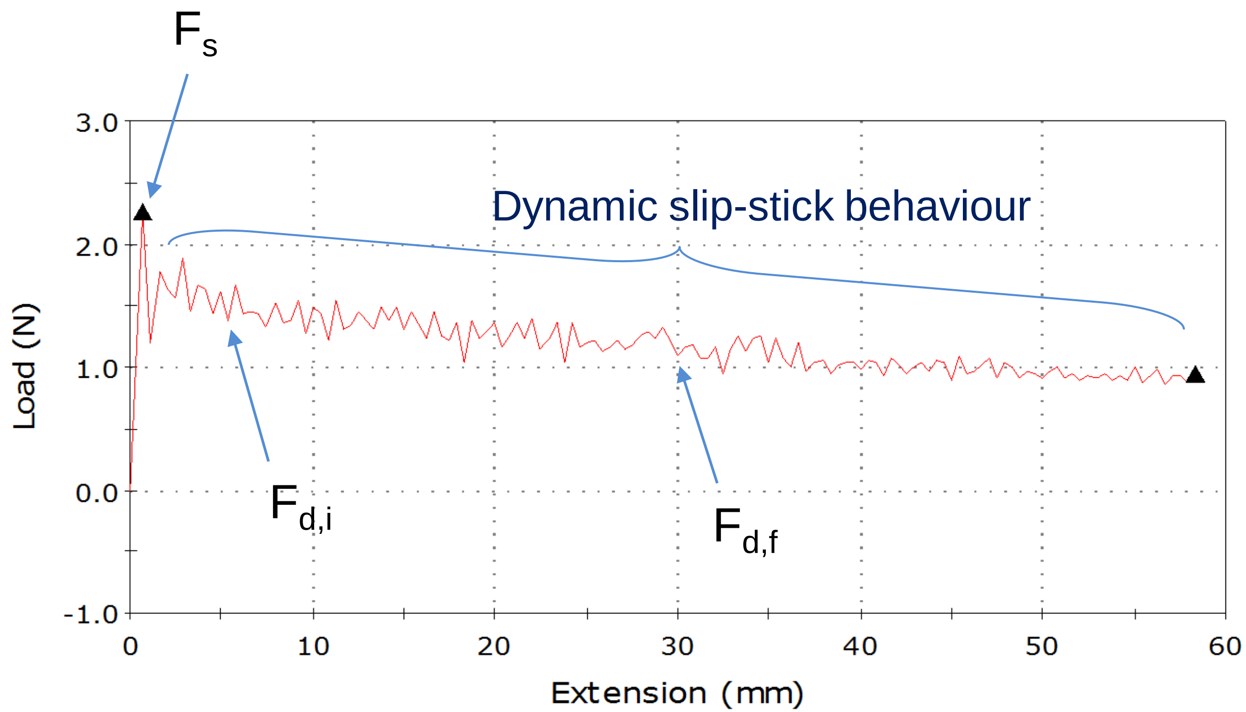
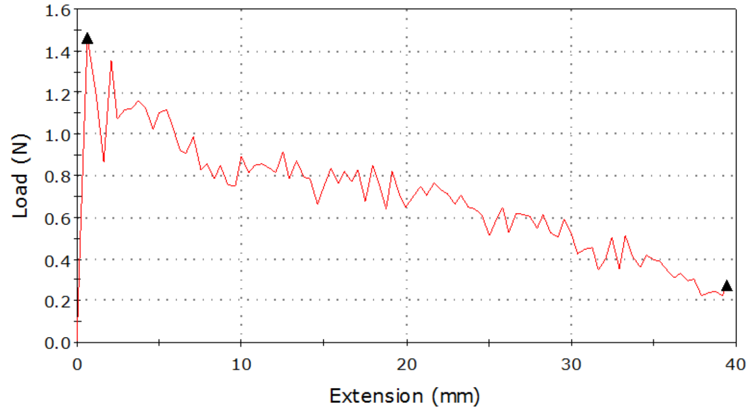
Turf Sample	Yarn Material	Tufts per m^2	Yarns per Tuft	Yarns per m^2	Pile Height, (mm)	Yarn Thickness, (mm)
1	Nylon	111,392	24	2,673,408	12	0.4
2	Nylon	145,200	10	1,452,000	13	0.4
3	Nylon	88,080	24	2,113,920	10	0.3
4	Polyethylene	147,000	8	1,176,000	15	1.5
5	Polyethylene	131,242	12	1,049,936	12	2
6	Polyethylene	151,200	10	756,000	13	1

Experimental results
Towed sled friction test – sample 1 dry



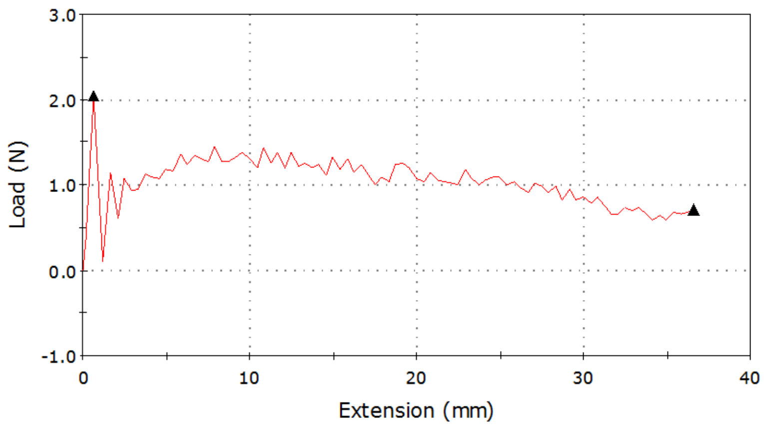
- Sled drawn at 500 mm/min
- F_s = peak force after initial load build up
- $F_{d,i}$ = initial dynamic force after 5mm of draw
- $F_{d,f}$ = final dynamic force after 30mm of draw
- F_d = Dynamic force is equal to average of $F_{d,i}$ and $F_{d,f}$
- Dynamic slip-stick behaviour observed

Least and most abrasive turfs (dry)



Sample 3

- Least abrasive (dry)
- High yarn density nylon turf
- Sharp decline in dynamic friction force in dynamic region



Sample 6

- Most abrasive (dry)
- Low yarn density polyethylene turf
- Dynamic friction force sustained in dynamic region

Summary of towed sled friction tests - DRY
Static and dynamic coefficients of friction

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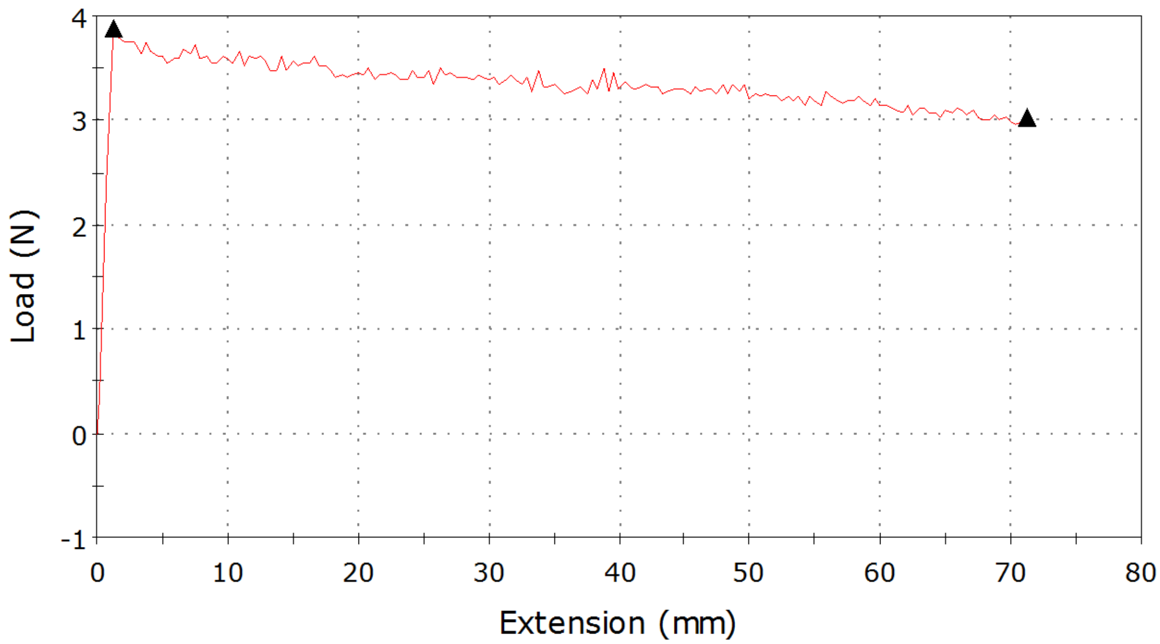
Turf Sample		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Direction 1 (Forces in N)	F_s	2.26	2.68	1.57	1.97	2.04	1.95
	$F_{d,i}$	1.61	1.63	1.37	1.03	1.84	0.77
	$F_{d,f}$	1.09	1.51	1.02	0.876	1.45	0.45
	F_d	1.31	1.5	1.14	0.875	1.6	0.58
Direction 2 (Forces in N)	F_s	1.87	2.53	1.75	2.08	1.84	2.26
	$F_{d,i}$	1.17	1.14	1.15	1.35	1.39	1.13
	$F_{d,f}$	0.79	0.88	0.62	1.09	0.95	1.23
	F_d	1.2	1.02	0.98	1.1	1.22	1.21
Direction 3 (Forces in N)	F_s	2.53	2.34	1.19	2.23	1.78	2.05
	$F_{d,i}$	1.95	1.58	0.65	1.45	1.21	1.19
	$F_{d,f}$	1.82	0.94	0.54	1	1.14	0.85
	F_d	1.83	1.22	0.60	1.23	0.99	1.15
Direction 4 (Forces in N)	F_s	2.46	2.15	1.47	2.21	2.15	2.25
	$F_{d,i}$	1.6	1.54	1	1.37	1.55	1.31
	$F_{d,f}$	1.24	1.15	0.516	1.26	1.15	0.88
	F_d	1.36	1.33	0.75	1.25	1.32	1.16
	$F_{s\ Average}$	**2.28**	**2.43**	**1.50**	**2.12**	**1.95**	**2.13**
	$F_{d\ Average}$	**1.43**	**1.27**	**0.87**	**1.11**	**1.28**	**1.03**
	μ_s	**0.14**	**0.15**	**0.09**	**0.13**	**0.12**	**0.13**
	μ_d	**0.09**	**0.08**	**0.05**	**0.07**	**0.08**	**0.06**

Values of dry coefficients of friction vary

Experimental results
Towed sled friction test – sample 1 wet



- **Sled drawn at 500 mm/min**
- **Peak force F_s much higher for wet tests**
- **Dynamic force F_d also much higher for wet tests**
- **Hence static and dynamic coefficients of friction are greater**
- **Dynamic slip-stick behaviour less peaky**

Summary of towed sled friction tests - WET
Static and dynamic coefficients of friction

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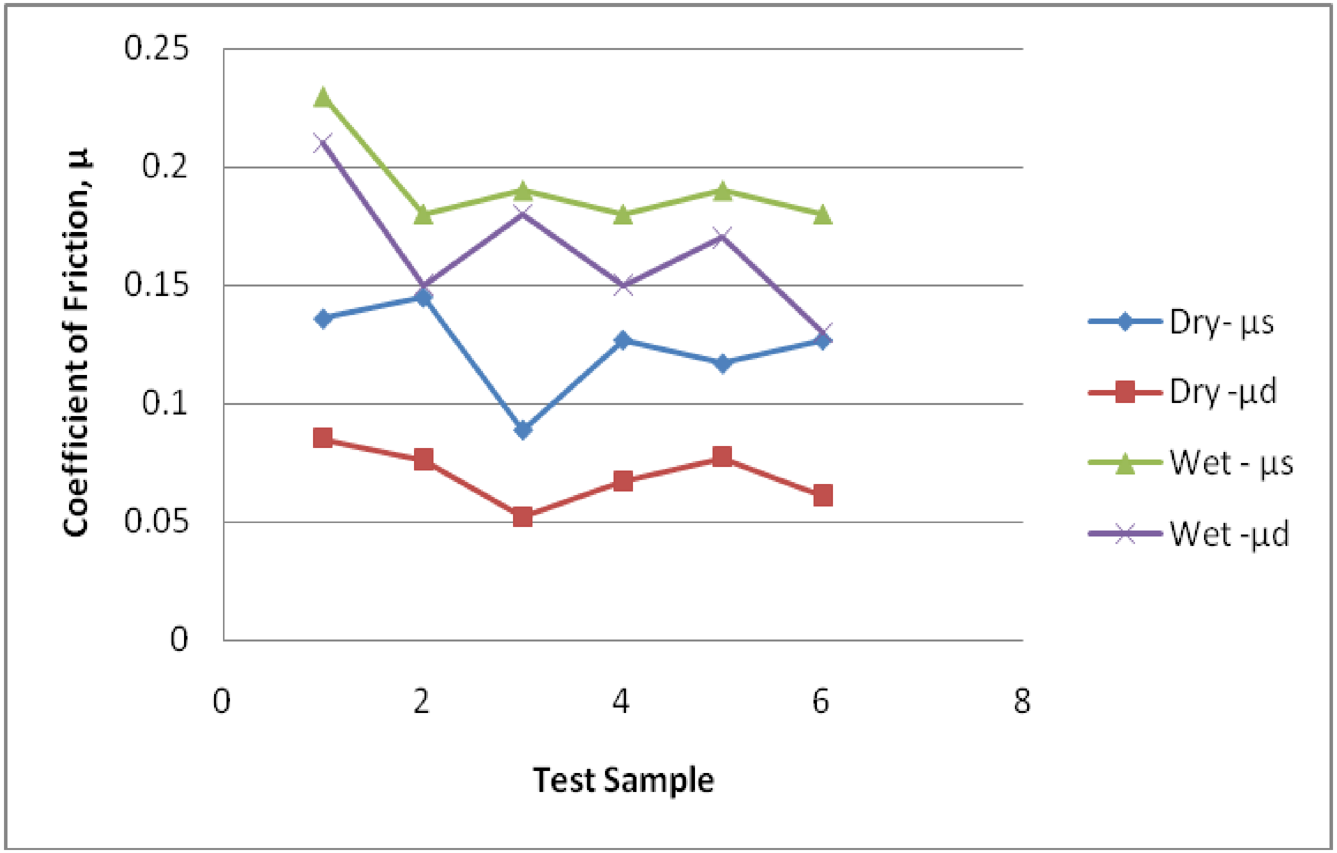
Turf sample		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Direction 1	F_s	n/a	n/a	n/a	n/a	n/a	3.35
	$F_{d,i}$	n/a	n/a	n/a	n/a	n/a	2.77
	$F_{d,f}$	n/a	n/a	n/a	n/a	n/a	2.34
	F_d	n/a	n/a	n/a	n/a	n/a	2.54
Direction 2	F_s	3.79	2.79	2.71	3.41	3.21	3.66
	$F_{d,i}$	3.61	2.69	2.62	3.06	3.35	3.13
	$F_{d,f}$	3.39	2.48	2.59	2.93	2.67	2.86
	F_d	3.51	2.52	2.79	3.02	2.90	2.97
Direction 3	F_s	3.50	2.92	4.45	3.15	2.42	1.99
	$F_{d,i}$	3.32	1.86	4.36	2.63	2.33	1.65
	$F_{d,f}$	2.97	1.88	3.83	2.16	2.14	1.51
	F_d	3.09	1.87	4.10	2.34	2.14	1.45
Direction 4	F_s	4.36	3.10	2.33	2.33	3.94	2.74
	$F_{d,i}$	4.34	3.09	2.20	2.20	3.96	1.82
	$F_{d,f}$	3.91	2.87	1.74	1.74	3.58	1.46
	F_d	3.96	2.91	1.94	1.94	3.63	1.65
	$F_{s\ Average}$	**3.88**	**2.94**	**3.16**	**2.96**	**3.19**	**2.93**
	$F_{d\ Average}$	**3.52**	**2.44**	**2.94**	**2.44**	**2.89**	**2.15**
	μ_s	**0.23**	**0.18**	**0.19**	**0.18**	**0.19**	**0.18**
	μ_d	**0.21**	**0.15**	**0.18**	**0.15**	**0.17**	**0.13**

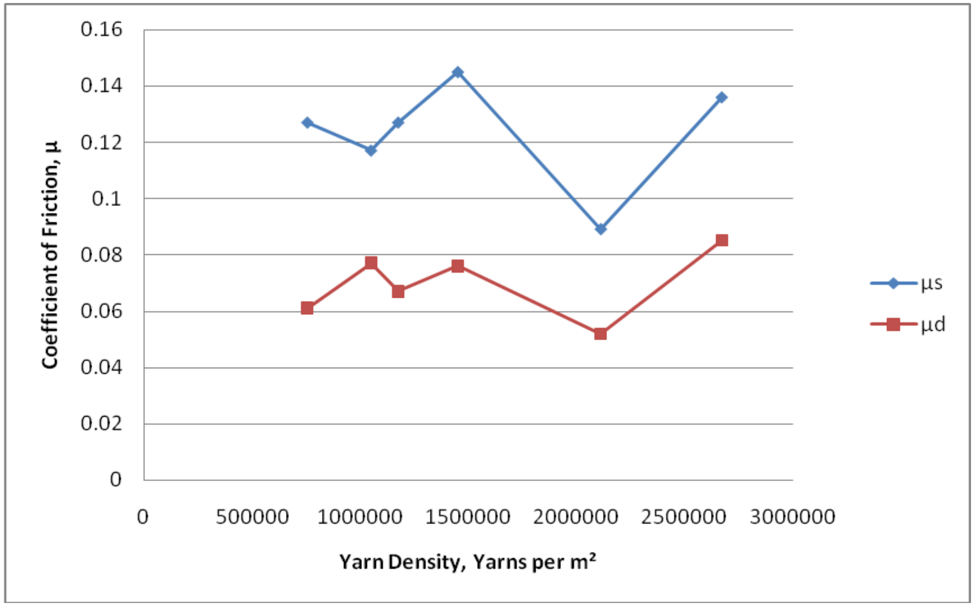
Values of wet coefficients of friction are similar

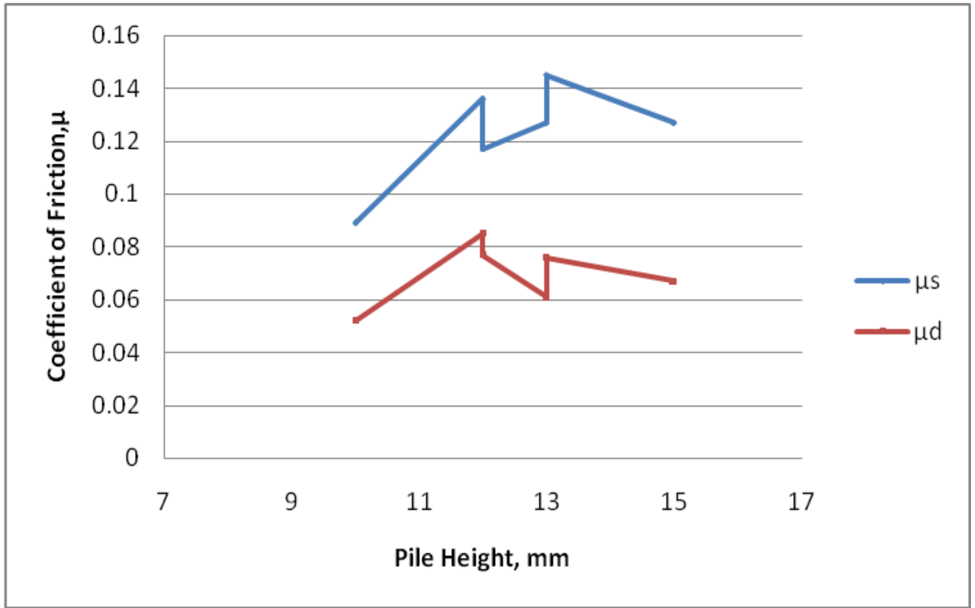
Static and dynamic coefficients of friction – wet and dry



- **Dry static coefficients of friction are greater than dry dynamic coefficients.**
- **Wet static coefficients of friction are greater than wet dynamic coefficients.**
- **Wet coefficients of friction are greater than dry coefficients of friction contrary to expectations for flat surfaces.**

Coefficients of friction (dry) versus yarn density and height of pile





Relative abrasiveness tests – dry and wet weight loss (g)

	Dry Conditions (Weight in grams)			Wet Conditions (Weight in grams)		
Turf Sample	Initial Weight	Final Weight	Weight lost	Initial Weight	Final Weight	Weight lost
1	2.1618	1.8196	0.3422	2.1588	1.8746	0.2842
2	2.1667	1.8387	0.3280	2.1556	1.8852	0.2704
3	2.1526	1.852	0.3006	2.1616	1.9847	0.1769
4	2.151	1.7604	0.3906	2.1377	1.9273	0.2104
5	2.1682	1.7784	0.3898	2.1339	1.8204	0.3135
6	2.1667	1.6991	0.4676	2.2108	1.9205	0.2903

- More compact turfs (Samples 1, 2 & 3) experience less weight loss when dry (14-20%) and wet (8-13%) than open turfs.
- More open turfs experience up to 22% weight loss (dry) and up to 15% (wet).

Relative abrasiveness (weight loss) versus yarn material

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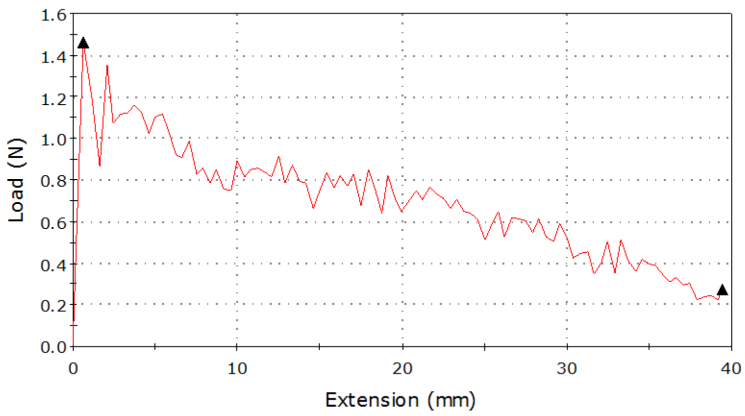
Turf Sample	Material	Weight lost g/m	
		Dry	Wet
1	Nylon	0.57	0.474
2	Nylon	0.547	0.451
3	Nylon	0.501	0.295
4	Polyethylene	0.651	0.351
5	Polyethylene	0.65	0.523
6	Polyethylene	0.779	0.484

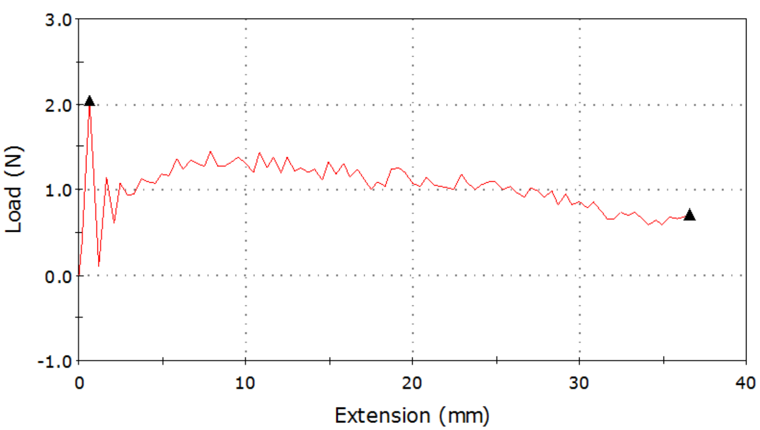
- Weak correlation between yarn material and relative abrasiveness when dry. Nylon is less abrasive.
- No correlation between yarn material and relative abrasiveness when wet.

Least and most abrasive turfs (dry)



Sample 3

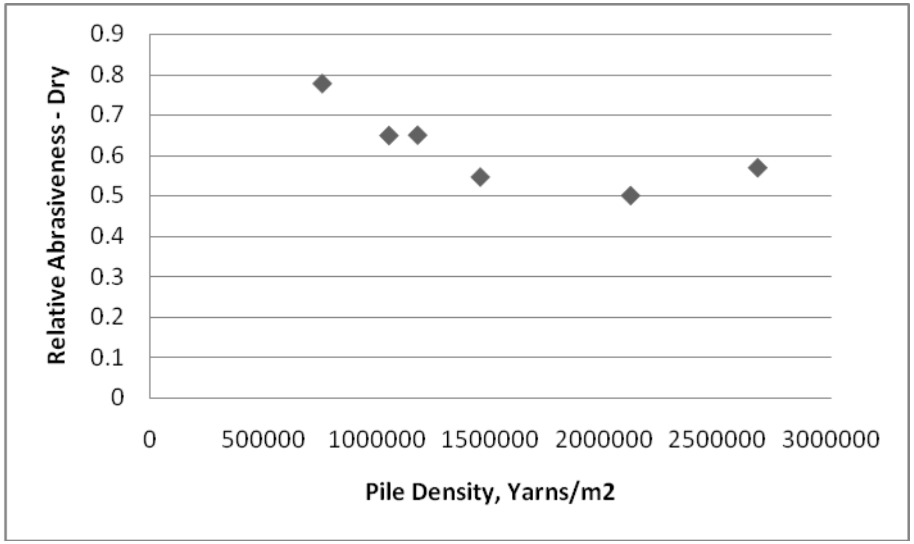
- **Least abrasive (dry)**
- **High yarn density nylon turf**
- **Sharp decline in dynamic friction force in dynamic region**



Sample 6

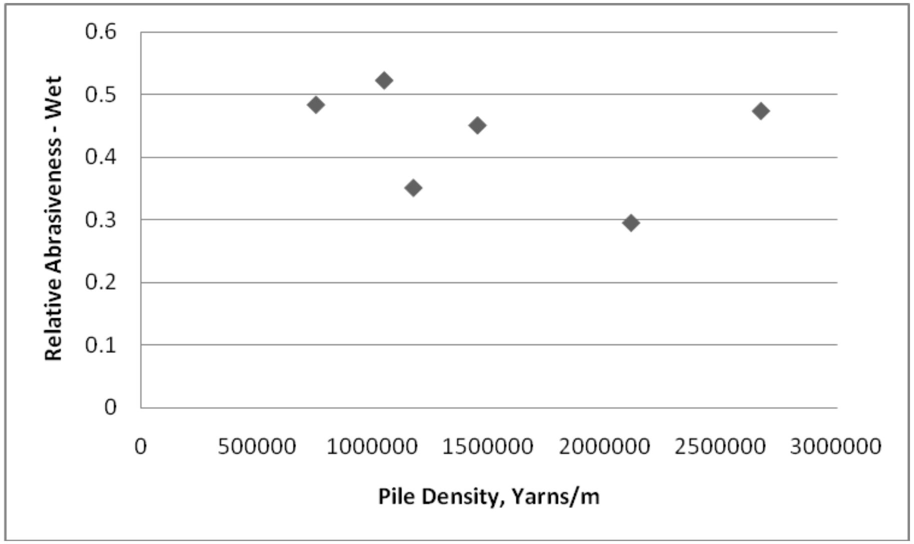
- **Most abrasive (dry)**
- **Low yarn density polyethylene turf**
- **Dynamic friction force sustained in dynamic region**

Abrasiveness versus pile density



DRY

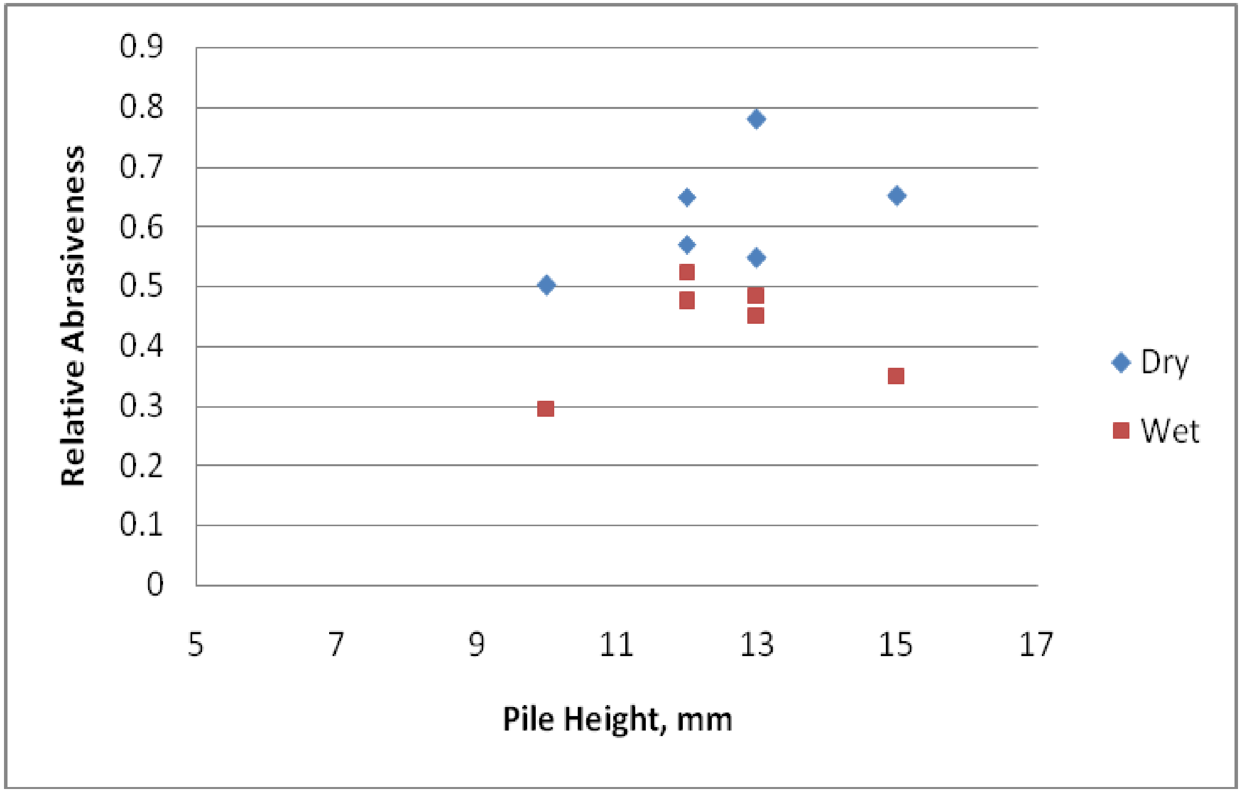
- **Turfs with higher yarn density are generally less abrasive**
- **Surface is more closely packed and smoother**



WET

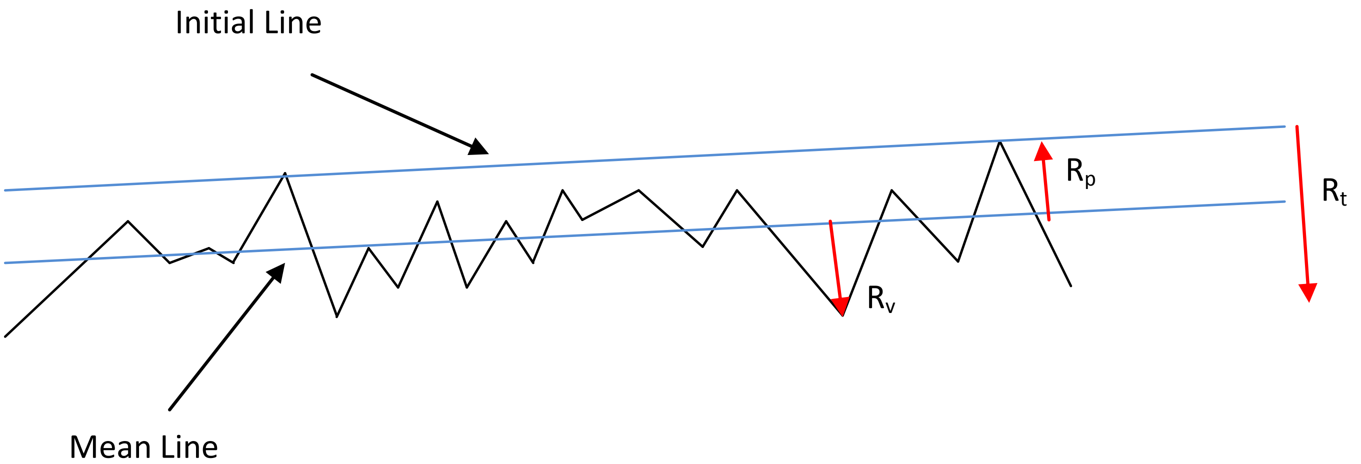
- **No correspondence between abrasiveness and yarn density in wetted turfs**
- **Water forms a lubricating film between yarns**

Abrasiveness versus pile height



- Turfs with shorter pile height tend to be less abrasive
- However shorter pile height turfs have higher yarn densities

Foam side profile and surface roughness



Surface roughness Ra based on deviations from the mean line (connecting two highest peaks from profile):

R_v = maximum valley depth
R_p = maximum peak height
R_t = maximum height of profile on the range
y_i = vertical distance from mean line to surface profile (taken every 0.5mm)
n= number of y_i values

Surface roughness = $Ra = \frac{1}{n}\sum_{i=1}^{n}|y_i|$

Abraded foam side profiles (SEM) & surface roughness Ra

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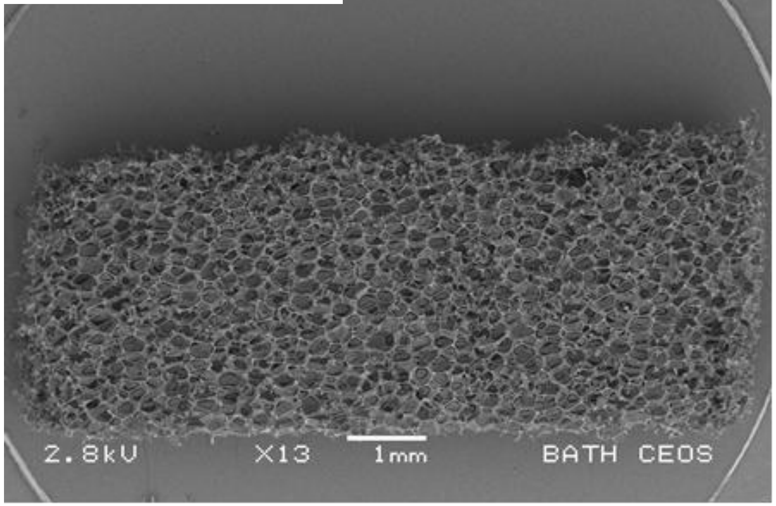
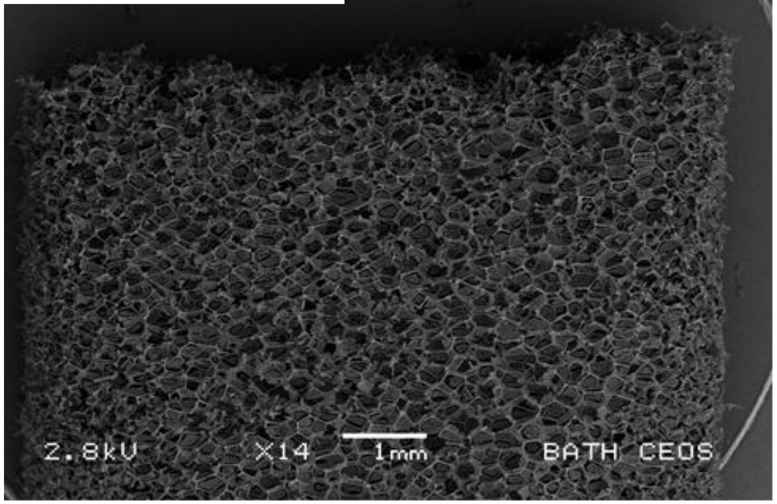
Sample 1 dry



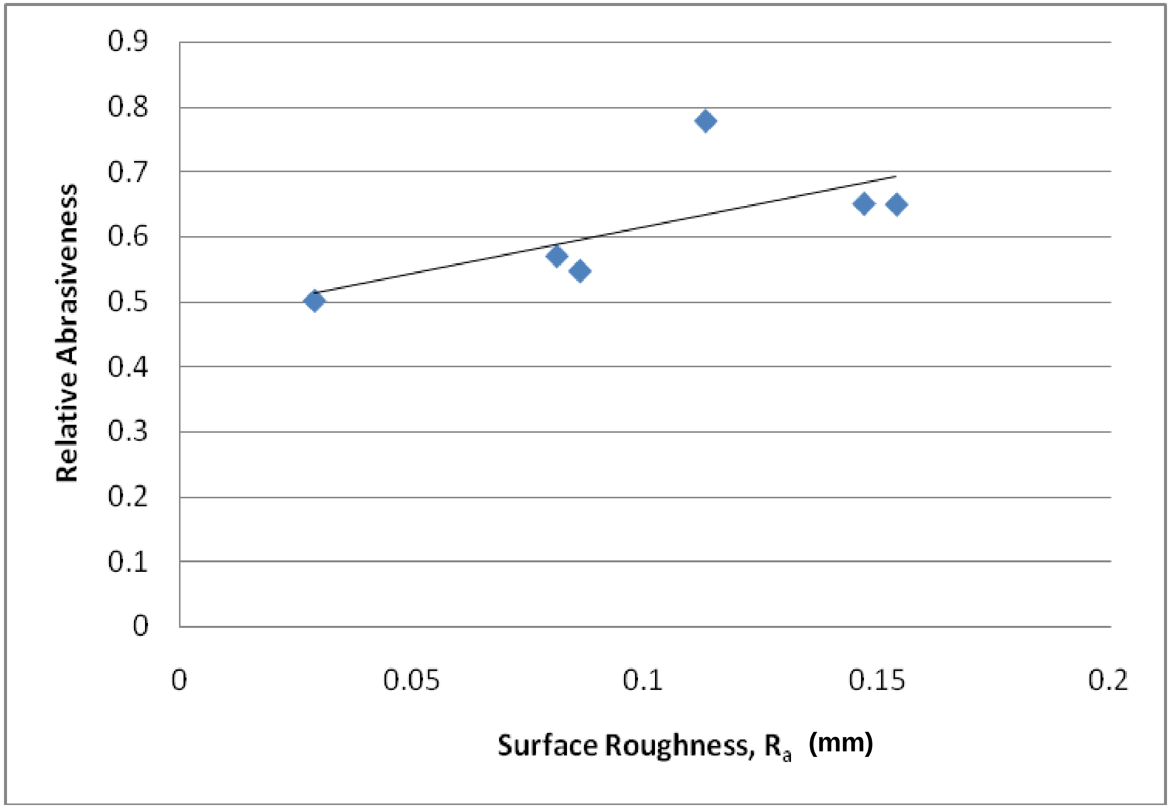
Sample 5 dry



Surface roughness R_a dry

Turf Sample	R_a, mm	R_v, mm	R_p, mm	R_t ,mm
1	0.081	-0.242	0.220	0.462
2	0.086	-0.354	0.217	0.571
3	0.029	-0.170	0.164	0.333
4	0.147	-0.409	0.234	0.643
5	0.154	-0.369	0.274	0.643
6	0.113	-0.548	0.286	0.833

Relative abrasiveness (weight loss) versus surface roughness Ra under dry conditions



- Relative abrasiveness (weight loss) linked to roughness of the surface
- Roughness of friable foam reflects the surface roughness of turfs
- Positive correlation between surface roughness and abrasiveness of turfs
- Abrasive turfs have a lower yarn density and coarser yarns

Conclusions

- The introduction of water to the synthetic turf systems reduced the abrasiveness of all turfs by an average of 30%.
- The introduction of water to the turf system increased the static and dynamic coefficients of friction from the towed sled friction test.
- The deviation of force in the slip-stick region of the towed sled friction test did not correlate with the abrasiveness of the turfs or their dynamic coefficients of friction in both wet and dry conditions.
- In all but one case the deviation of force during the stick slip period of the towed sled friction test was lower when wet, most significantly for the samples with short, dense, nylon yarns, indicating a link between a smooth slip-stick region and low abrasion.
- The abrasiveness of artificial turf did not correspond to a high dynamic coefficient of friction.
- Artificial turfs with high pile density were less abrasive, confirmed by wear trails in abraded foam, because their smoother surfaces contained tighter yarns.

Greetings from Bath!

Surface roughness

Static and dynamic friction coefficients versus relative abrasiveness (g/m)

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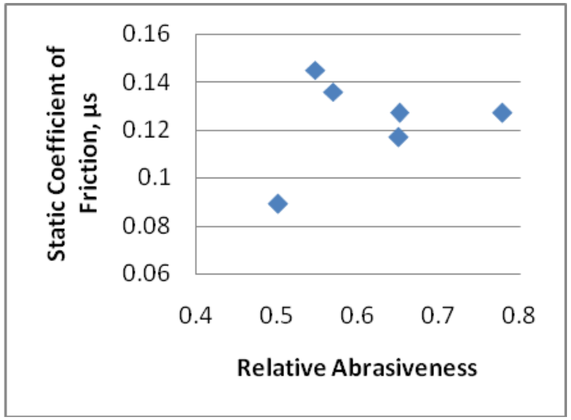
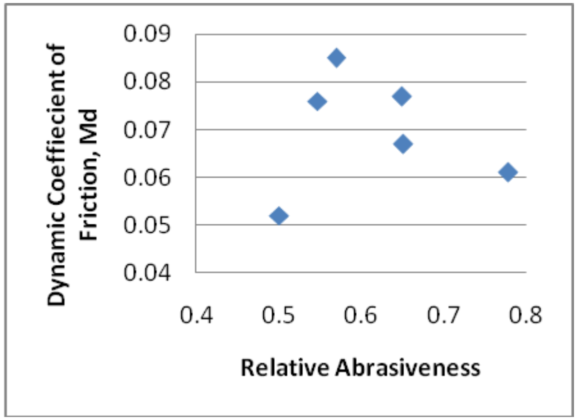
STATIC FRICTION COEFFICIENT μ_S

DYNAMIC FRICTION COEFFICIENT μ_D

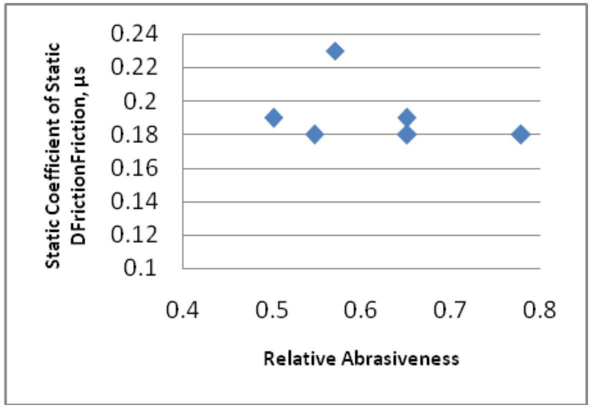


μ_s dry vs. relative abrasiveness

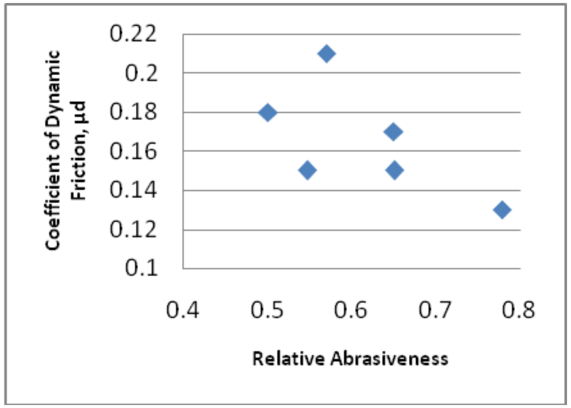


μ_d dry vs relative abrasiveness

DRY



μ_s wet vs relative abrasiveness



μ_d wet vs relative abrasiveness

WET