Advanced Materials for Sports Technology
www.icsst14.com

STRATEGY TOWARDS NEXT GENERATION ARTIFICIAL TURF SURFACES WITH LOWER RISK OF SKIN ABRASION INJURY

S.P. Tay[1], X. Hu*[1], P. Fleming[2], S. Forrester[3]

[1] School of Materials Science and Engineering, Nanyang Technological University, 50 Nanyang Avenue, S639798, Singapore
[2] Civil and Building Engineering Department, Loughborough University, Loughborough LE11 3TU, UK
[3] Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, Loughborough, LE11 3TU, UK

Abstract

One of the main concerns with artificial turf is the increased incidents of skin abrasions compared to natural grass. The aim of this study is to modify the main component material of the artificial turf yarns with grafted-from sulfobetaine methacrylate (SBMA) brushes so as to reduce skin-abrasion of these surfaces; and to investigate the significance of tribo-pairs in determining skin-friendliness of a surface. Standard stainless steel tribometer tips were not able to discern the effect of surface grafting whereas frictional measurements carried out using FIFA-recommended skin surrogates showed a decrease in the coefficient of friction (μ) of up to 77% from 1.33 to 0.30 for hydrated SBMA-modified substrates. This study introduced the use of an appropriate tribo-pair for skin-surface friction measurement that can potentially be used for quantifying the skin-friendliness of artificial sports surfaces. It has also provided a strategy that could lead to next generation artificial turfs with significantly reduced risk of abrasion injury.

1. Introduction

Artificial turf – a system comprising grass-like polymeric yarn carpets and rubber or sand infill – is becoming increasingly popular as an alternative playing surface for field sports due to its resistance to harsh weather conditions and ability to cater for increased usage hours. Despite the growing number of installations of artificial turfs around the world, many users still prefer playing on natural grass, citing negative perceptions of the synthetic surfaces.

Of which, artificial turf surfaces are often seen as abrasive – hence the introduction of the term “turf burns” which defines skin abrasion injuries sustained from playing on artificial turf surfaces [1], [2]. Although softer polyolefins yarns were introduced in the 1970s to replace tougher polyamides [3], recent epidemiological studies still show higher rates of skin abrasions suffered on artificial turfs as compared to natural grass fields [4]–[6]. Meyers et al., while investigating the injuries sustained by high school footballers, found that even when the artificial turf product tested was promoted as “nonabrasive”, the incidences of minor injuries such as abrasions, contusions and lacerations while playing on artificial turfs were significantly higher than that on natural fields (42.5% vs. 29.6% of all injuries, respectively) [4].

Apart from the adoption of polyolefins for the manufacturing of artificial turf yarns, there has been little progress in developing turf systems with reduced skin abrasiveness. Patented technologies claiming skin-friendly artificial turf yarns mostly relate the reduced abrasiveness to the use of polyolefines [7]–[10]. In addition, frictional assessments to support their skin-friendly claims are also lacking. The first part of this study is hence focused on material engineering; modifying the surface properties of polyolefin substrates to investigate its effect on skin-friction.

Currently, the most relevant testing method of skin abrasion on artificial turf surfaces is the FIFA-08 test, developed by the governing body as part of a quality concept for the accreditation of artificial turfs. The lab-based test involves the use of a Securisport Sports Surface Tester that runs a silicone skin-attached foot across a prepared artificial turf system to measure its coefficient of friction and abrasive value [11]. According to FIFA, the product is satisfactory if the coefficient of friction falls between 0.35 – 0.75 and skin abrasion value of ± 30%. There also exists a standard testing procedure published by the American Society for Testing and Materials (ASTM) – F1015 that assigns an Abrasiveness Index to the tested surface by measuring the decrease in mass of a friable foam block after being pulled across a completed turf system under a constant normal load [12]. However, the ASTM standard does not provide an interpretation of the Abrasiveness Index in relation to skin-friendliness and the foam block used is a poor representation of the human skin.

The above-mentioned methods measure the frictional properties of complete artificial turf systems but there has yet to be standard procedure for assessment of the skin-friendliness of turf yarns which may be beneficial in the product development stages. Therefore, the second objective of this study is to investigate a bench-top test method that allows for the friction measurement of the modified polypropylene samples – a characterization method for prepared yarns prior to carpet-assembly.

2. Experimental Work

2.1. Materials

Commercial polypropylene (PP) films were purchased from Goodfellow Inc. of Cambridge, UK. The samples were cleaned by ultrasonication with acetone for three repetitions to remove any residual organic contaminants and allowed to dry at room temperature. Sulfobetaine methacrylate (SBMA) monomer was purchased from Sigma-Aldrich together with photoinitiator benzophenone (BP). All other solvents were used as received.

2.2. UV-induced Surface Grafting

Surface grafting of poly-SBMA onto the PP substrates was carried out using the Incure F200P Ultraviolet (UV) Flood Curing Lamp equipped with a metal halide lamp (600W) at an irradiation intensity of 50mW/cm^2 (± 5mW/cm^2). The surface grafting experiments were conducted using an adapted approach from Yang and Ranby [13]–[16]. UV-induced surface grafting proceeded via the free-radical polymerization of SBMA monomers onto PP substrates, using BP as a photoinitiator. UV irradiation durations of 300s and 900s were used in this study to vary the extent of polymerization. After grafting, the modified PP samples were washed thoroughly in a hot water bath to remove homopolymers and residual monomers. The washed samples were then dried in vacuo overnight.

2.3. Characterization

The poly-SBMA grafted PP samples (pSBMA-g-PP) were characterized by Fourier Transform Infrared Spectroscopy–Attenuated Total Reflectance (FTIR-ATR) using the Perkin Elmer Frontier, to detect the presence of key compounds. Scanning was carried out from 4000cm^{-1} to 650cm^{-1} for 16 scans with a resolution of 2cm^{-1}. Field Emission Scanning Electron Microscopy (JEOL JSM-6340F) was used to image the polymer brushes grafted onto the substrates, at an accelerating voltage of 5kV. The water contact angles of the surfaces were measured using Analytical Technologies FTA32.

2.4. Friction Measurements

The coefficients of friction (μ) of the samples were measured using the CSM Instruments Microtrobometer with standard 1cm-diameter stainless steel balls and 1cm-diameter round tips of L7350 silicon skin.. The silicon skin purchased from Maag Technic AG, Switzerland is the FIFA-approved counter surface for skin friction assessment of artificial turf surfaces in accordance to their Handbook of Test Methods for Football Turf [11]. Frictional measurements were performed at room temperature with a normal load of 0.2N, rotational radius of 1.00mm, and linear speed of 5cm/s for 2000 cycles. The samples were tested either in dry or hydrated states where the hydrated samples were submerged in deionized water for 2h and excess surface moisture removed using a piece of filter paper prior to testing.

3. Results and Discussion

3.1. Surface Modification of Polypropylene

FTIR-ATR analysis of the pSBMA-g-PP samples of different irradiation durations against the PP substrate detects the presence of characteristic absorption peaks at 751cm^{-1} (C-S), 1043cm^{-1} (S=O) and 1722cm^{-1} (C=O) for the surface-modified samples, indicating successful grafting of pSBMA through the UV-induced process. The peak intensities increase with increasing irradiation duration with the detection of the broad surface water peaks at 3445cm^{-1} for samples irradiated for 900s, suggesting the hydrophilic nature of the sample.

The grafting of SBMA polymer brushes is evident from the FESEM images shown in Figure 1. The formation of polymer brushes can be seen as globules on the sample surfaces – a retracted state of the brushes under dry conditions. The grafting density of the polymer globules on the surface increases from 300s to 900s of irradiation duration and the growth in globule size also implies longer polymer brushes.

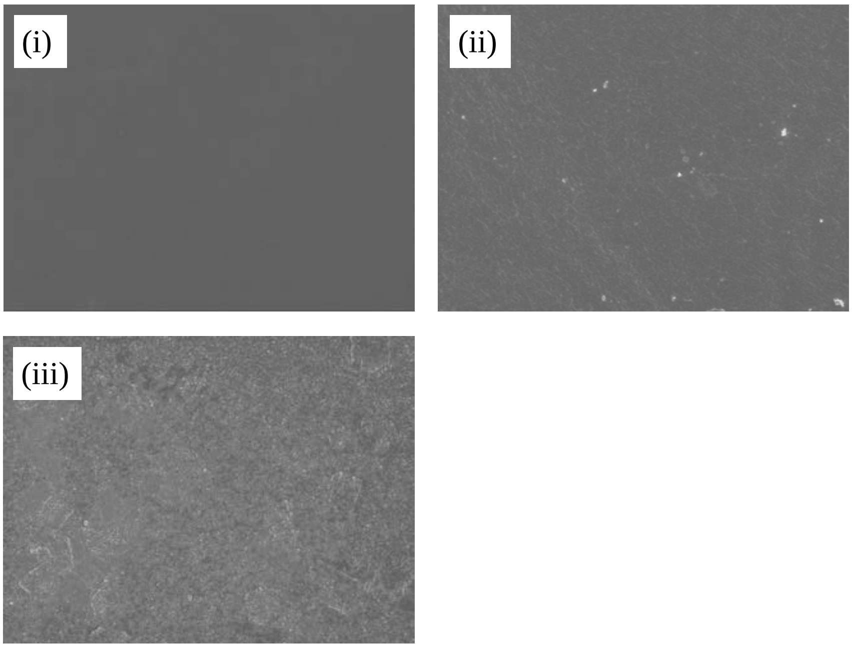

Figure 1. FESEM images of (i) PP substrate and pSBMA-g-PP samples irradiated for (ii) 300s and (iii) 900s. Images captured at a magnification of 1000 times at an accelerating voltage of 5kV.

With increasing pSBMA grafting, the hydrophilicity of the surfaces increases, evident from the decrease in contact angle from 90° (±2°) to 29.3° (±5°). The hydrophilic nature of the modified surface is inherent from the pSBMA brushes tethered to the PP substrate. Electrostatic interactions between the zwitterionic charged entities on the SBMA monomer and polar water molecules result in strong binding forces that give pSBMA its superior hydration ability [17].

3.2. Frictional Properties of pSBMA-g-PP

The effects of surface modification of PP substrates on their frictional properties were investigated using stainless steel and silicone skin tips. Stainless steel is commonly used in tribological studies of surface friction and we have selected FIFA-recommended L7350 silicone skin as a comparison to investigate the implications of counter-surfaces on frictional results. As it is not possible and unethical to perform frictional measurements on live subjects, the skin surrogate was chosen as silicone provides the closest replication of skin frictional behaviour amongst common materials [18].

When measured under dry conditions using the stainless steel tip, the coefficients of friction (μ) of the modified PP substrates did not show a significant trend with increasing irradiation durations (Figure 2i). This can be attributed to the ploughing mechanism of friction between hard and soft surfaces [18], [19], where the stainless steel tips dig into the polymer samples resulting in the formation of a wear track and corresponding debris – evident on all tested samples even at low normal loading. For measurements performed using the L7350 silicone skin surrogates, the comparatively higher μ values obtained are due to friction resulting from adhesion between the interacting surfaces. The slight increase in μ with increased surface modification may be due to the larger pSBMA globule size that results in a larger effective surface area of interaction (interlocking) between the modified samples and the L7350 tip.

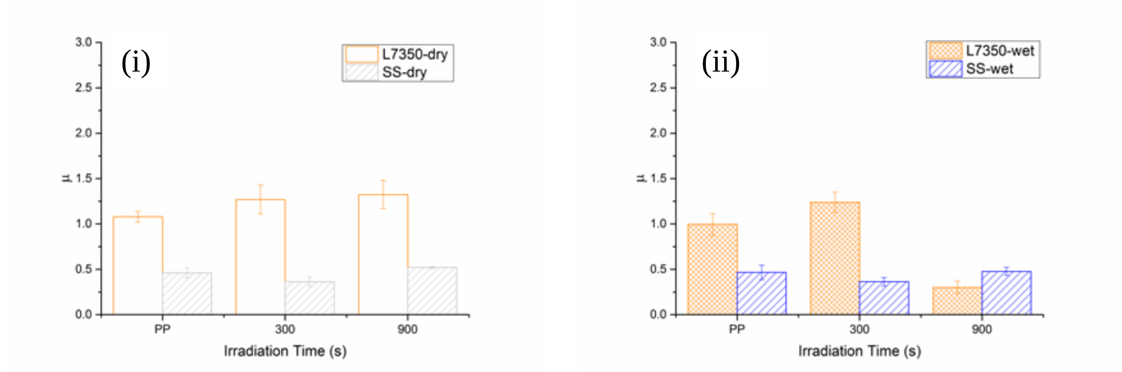

Figure 2. Comparison of the coefficients of friction (μ) of (i) dry and (ii) hydrated PP substrates and pSBMA-g-PP samples by testing with stainless steel and L7350 silicone skin tips.

The μ value for the highly-modified samples (900s) is reduced by 77.3% with surface hydration when measured using the L7350 silicone skin tips (Figure 2ii). The hydrated pSBMA-g-PP sample has a μ value 77.2% lower than the "hydrated" PP substrate. This can be attributed to the strong hydrating properties of the pSBMA brushes. In the presence of water, the superhydrophilic polymer brushes swell and extend into the solvent, binding the water molecules via strong electrostatic forces to form a stable hydrated layer. Even with the removal of surface water prior to the frictional measurements, the strongly-held hydrated layer by covalently-tethered pSBMA brushes remains – acting as a lubricating layer that significantly reduces friction. The hydrophobic PP substrate and lightly-modified sample were unable to bind enough water for the formation of a lubricating hydrated layer. On the other hand, the stainless steel tips showed similar μ values as that measured under dry conditions. This may be due to the ploughing mechanism dominating the frictional interaction between the tribo-pairs, with the large hardness variation between stainless steel and the polymeric samples. In addition, the standard stainless steel tribological tips were insensitive to the pSBMA-modification of the samples – unable to distinguish between PP substrates and grafted surfaces. This implies that stainless steel may not be a suitable test probe for the characterization of skin-friendly surfaces in the context of reduced friction. The non-biofidelicity of stainless steel to the human skin highlights how off-the-shelf testing standards may not be relevant when used to determine frictional properties of surfaces in application to skin-surface interactions.

4. Conclusions

Sulfobetaine methacrylate polymer brushes were grafted onto polypropylene substrates via photo-induced polymerization as a strategy to address the abrasive properties of polyolefin artificial turf yarns. The tribological performances of the modified samples were investigated in the context of skin-friendliness by frictional measurements using the FIFA-approved L7350 silicone skin under both dry and hydrated conditions. The results showed that with sufficient pSBMA grafting, the effect of surface hydration can reduce friction up to 77.3%. The study also compared frictional values measured using standard stainless steel tribological probes to highlight the importance of appropriate test methods when determining the skin-friendliness of surfaces. Unlike the silicone skin surrogate, the stainless steel tips were poor representations of human skin and were unable to differentiate pSBMA-modified samples from PP substrates through the tribological studies. The surface modification strategy together with the bench-top frictional measurement presented in this work may pave the way to the next generation of artificial turf surfaces – addressing product development needs for skin-friendly surfaces and intermediate product assessment tools.

References

[1] GoHockey, “Sports Medicine: How to treat turf burns.” [Online]. Available: http://gohockey.com/sports-medicine-how-to-treat-turf-burns/. [Accessed: 08-Sep-2014].

[2] Medical Dictionary for the Health Professions and Nursing, “‘turf burn,’” 2012. [Online]. Available: http://medical-dictionary.thefreedictionary.com/turf+burn. [Accessed: 08-Sep-2014].

[3] P. Fleming, “Artificial turf systems for sport surfaces: current knowledge and research needs,” Proc. Inst. Mech. Eng. Part P J. Sport. Eng. Techonology, vol. 225, pp. 43–62, 2011.

[4] M. C. Meyers and B. S. Barnhill, “Incidence, causes, and severity of high school football injuries on FieldTurf versus natural grass: a 5-year prospective study,” Am J Sport. Med, vol. 32, no. 7, pp. 1626–1638, 2004.

[5] C. W. Fuller, R. W. Dick, J. Corlette, and R. Schmalz, “Comparison of the incidence, nature and cause of injuries sustained on grass and new generation artificial turf by male and female football players. Part 1: match injuries,” Br J Sport. Med, vol. 41 Suppl 1, pp. i20–6, 2007.

[6] C. W. Fuller, L. Clarke, and M. G. Molloy, “Risk of injury associated with rugby union played on artificial turf,” J. Sports Sci., vol. 28, no. 5, pp. 563–570, 2010.

[7] E. Buriani and F. Zenoni, “Thermoplastic synthetic fiber for producing artificial grass mats or the like, process for the production thereof and mats incorporating said fiber.” Google Patents, 2008.

[8] W. M. H. Olde, G. B. Slootweg, D. G. F. J. Van, L. J. J. W. Welzen, and C. A. M. J. P. Widdershoven, “Artificial fibre as well as an artificial lawn for sports fields provided with such fibre.” Google Patents, 2004.

[9] R. Luijkx, “Artificial grass.” Google Patents, 2013.

[10] F. Atsma and D. Wildschut, “Yarn for an artificial turf ground cover, artificial turf ground cover and playing field including such a yarn and method for producing such a yarn.” Google Patents, 2009.

[11] Fédération Internationale de Football Association FIFA, “FIFA Quality Concept for Football Turf - Handbook of Test Methods.” 2012.

[12] A. International, “ASTM Standard F 1015, 2003 (2009),” Standard Test Method for Relative Abrasiveness of Synthetic Turf Playing Surfaces. ASTM International, West Conshohocken, PA, 2009.

[13] W. Yang and B. Rånby, “Bulk surface photografting process and its applications. I. Reactions and kinetics,” J. Appl. Polym. Sci., vol. 62, no. 3, pp. 533–543, 1996.

[14] W. Yang and B. Rånby, “Bulk surface photografting process and its applications. II. Principal factors affecting surface photografting,” J. Appl. Polym. Sci., vol. 62, no. 3, pp. 545–555, 1996.

[15] W. T. Yang and B. Rånby, “The role of far UV radiation in the photografting process,” Polym. Bull., vol. 37, no. 1, pp. 89–96, 1996.

[16] B. Rånby, W. T. Yang, and O. Tretinnikov, “Surface photografting of polymer fibers, films and sheets,” Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms, vol. 151, no. 1–4, pp. 301–305, 1999.

[17] S. Chen, L. Li, C. Zhao, and J. Zheng, “Surface hydration: Principles and applications toward low-fouling/nonfouling biomaterials,” Polymer (Guildf)., vol. 51, no. 23, pp. 5283–5293, 2010.

[18] M. Zhang and A. F. Mak, “In vivo friction properties of human skin,” Prosthet Orthot Int, vol. 23, no. 2, pp. 135–141, 1999.

[19] K. Holmberg, Coatings Tribology: Properties, Techniques, and Applications in Surface Engineering. Elsevier, 1994, p. 442.