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The effects of natural and artificial UV exposure on the physical properties of synthetic turf used for various sports fields

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Abstract. Since its induction at the Astrodome, in 1965 synthetic turf has been improved and adapted to now be accepted as a playing surface for a variety of sports. These sports include Rugby, Soccer and Field hockey. As synthetic turf is most likely destined for outdoor use it will be subject to Ultra Violet (UV) degradation in the form of Ultra Violet light band A (UVA), Ultra Violet light band B (UVB) or a combination of both. Synthetic turf is a polymer based material, specifically polyethylene for this study. For this reason it is useful to investigate how polyethylene degrades due to UV. Absorbed UV causes a break in the intermolecular bonds of the polyethylene, which leads to cracking, inhibiting the material to perform as initially intended. Colour change is also a consequence of extended exposure to UV. Various UV stabilizers are used, by manufacturers, in order to slow this process down. These however are largely dependent on the type of UV being exposed.

Natural UV testing of new materials is time consuming, thus accelerated weathering testers such as the QUV/spray machines are used to simulate artificial UV and accelerate this process. A correlation between natural and artificial UV is sometimes difficult to achieve. For this reason both natural and artificial UV exposures were performed in this study. Through these various exposures to the samples, it was possible to indeed confirm that UV degrades synthetic turf as well as the processes leading to it. It was also confirmed that the samples would meet the sporting standards set out by the Internaltional Rugby Board (IRB), Fédération Internationale de Football Association (FIFA) and International Hockey Federation (FIH), for use as a playing surface. A correlation between natural and artificial UV in terms of colour change was achieved with UVA being found as the predominant type of natural UV exposure in Johannesburg, during the winter months. Solutions were also provided to mitigate the degrading effects of UV on synthetic turf, these solutions would however need further investigation

Keywords. UV, UV degradation, UV exposure, synthetic turf, synthetic yarn

Introduction

What is natural UV? Natural UV, for the purposes of this study will be defined as UV that is emitted by the sun. Of the four types of UV emitted by the sun, only two eventually make it to the earth’s surface, these being UVA and UVB. UVA makes up 95% of the UV that reaches the earth’s surface and is characterized as the UV that allows your skin to tan. UVB on the other hand is characterized as the UV that causes human skin to burn causing skin cancer, due to its shorter wavelengths.

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The intensity of UV exposure is affected by a variety of factors such as latitude, time of year, time of day, altitude, ozone levels and cloud cover [2]. What is artificial UV? Artificial UV, for the purposes of this study will be defined as UV that is emitted by the fluorescent bulbs used in the QUV/spray accelerated weathering tester. This piece of equipment does not try to replicate the entire spectrum of sunlight but rather the damaging effects of sunlight [3]. Through this piece of equipment it is possible to simulate months or years of outdoor exposure within weeks or months in the lab.

Two different types of lamps were used, UVA-340 and UVB 313. UVA-340 lamps emit a spectrum much the same as natural sunlight, with UVB-313 emitting a harsher spectrum [4]. What is synthetic turf? Synthetic turf is a polymer based material made using either polyethylene or polypropylene. Synthetic turf is formed through an extrusion process. The polymer is mixed together with a host of chemical additives such as colour dyes and UV stabilizers to form either a monofilament yarn or fibrillated yarn [5]. Many types of UV stabilizers can be used such as: UV reflectors, UV absorbers, Quenchers as well as HALS [6].

How does UV degrade synthetic turf? Synthetic turf degrades due to UV through a process known as photochemical degradation [7]. To understand how photochemical degradation occurs one needs to understand the three principles which govern this degradation. They are the Grotthus-Draper law, Stark-Einstein law and the bond dissociation energy [7]. Through these principles UV has the greatest potential to break the intermolecular bonds, due to its higher energy. Heat, oxygen and moisture then cause degradation through secondary reactions [8]. UVB with its shorter wavelengths and higher energy will have the greatest potential of breaking bonds when compared with UVA. Free radicals which exist in the synthetic turf due to impurities introduced during the manufacturing process attract and absorb the UV. The energy then excites and promotes the electrons from the highest occupied molecular orbital to the lowest unoccupied molecular orbital. This jump of electrons causes a rearrangement of atoms at this point with subsequent scission or crosslinking leading to degradation [9].

Through the degradation process the synthetic turf experiences the following effects to its physical properties. Cracks and crazing throughout the sample surface causing the material to become brittle. Gloss loss and chalking which through chemical reactions causes the material to lose its original colour [10]

1. Research methodology

The research was broken down into three different types of UV exposure. Each type of exposure then had three tests performed both pre and post UV exposure for comparison. The three tests performed were a tensile strength test (BS EN 13864:2004), a colour change test (BS EN 20105-A02:1995) as well as micrographs taken using a scanning electron microscope (SEM). Through the various tests the following properties were compared: breaking force, percentage elongation, linear density and colour change. The samples used for the exposures are listed in Table 1 and supplied by Sportslabs Ltd.

Table 1. Synthetic yarn samples supplied by Sportslabs Ltd

Yarn SL Reference	Name	Yarn type
5644	MN Slide - Diamond Bright Green	Monofilament
5646	MN Ultra - White	Monofilament
5655	FB Ultra - Black	Fibrillated
5656	FB Ultra – Cardinal Red	Fibrillated

1.1. Exposure type 1 – Sportslabs Ltd.

The first type of exposure was performed by Sportslabs Ltd. The samples were exposed to artificial UV according to the BS EN 14836:2005. These results were compared against the standards set out by the IRB, FIFA and FIH for UV degradation of synthetic turf. It should be noted that the sporting bodies require samples to be exposed to the full period of artificial UVA in order to be compared to their standards.

1.2. Exposure type 2 – 80 days of natural UV exposure

The second type of exposure consisted of exposing the samples to 80 days of natural UV in Johannesburg, South Africa from the end of June till the beginning of September. The following climatic conditions were recorded for the exposure period: moderate to high levels of UV, clear skies, low rainfall, relatively dry conditions and mild to low temperatures.

1.3. Exposure type 3 – Equivalent 80 days artificial UVA and UVB exposure

The third type of exposure consisted of exposing the samples to an equivalent 80 days of artificial UVA and UVB. The equivalent times were calculated using the radiation rates for the two types of lamps used in the QUV machine as well as the kLangley rating for Johannesburg (170 kLangley/year)[11]. This gave the following equivalent exposure times:

- UVA @ 0.89 W/m^2 for 732 hours
- UVB @ 0.62 W/m^2 for 840 hours

2. Results

The results are presented in table format using percentages for each property investigated, for the various exposures. What should be noted is that a positive percentage indicates a gain in that particular property from pre to post UV exposure, with a negative percentage indicating a loss.

2.1. Exposure type 1 – Sportslabs Ltd.

Table 2. Percentage change in sample characteristics for artificial UVA, Sportslabs Ltd.

Sample	Tensile strength	Percentage elongation	Linear density	Colour change
5644	-17.36%	-17.41%	2.35%	Lighter
5646	-4.38%	6.49%	4.17%	Lighter
5655	-5.91%	6.42%	2.50%	Lighter
5656	-1.96%	6.53%	2.11%	Lighter

Table 3. Percentage change in sample characteristics for artificial UVB, Sportslabs Ltd.

Sample	Tensile strength	Percentage elongation	Linear density	Colour change
5646	-4.38%	6.49%	4.17%	Lighter

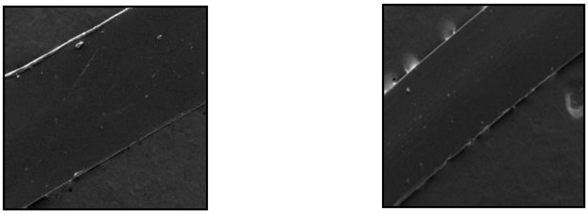

Figure 1. SEM micrograph of sample 5644 both pre and post artificial UVA exposure

2.2. Exposure type 2 – 80 days of natural UV exposure

Table 4. Percentage change in sample characteristics for 80 days of natural UV exposure

Sample	Tensile strength	Percentage elongation	Linear density	Colour change
5644	-1.83%	-11.56%	6.85%	No change
5646	4.73%	2.91%	-2.86%	No change
5655	2.27%	-8.61%	0.90%	No change
5656	-2.62%	-12.68%	3.87%	Lighter

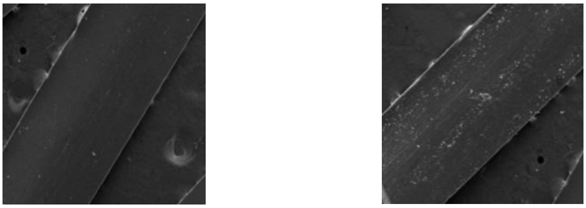

Figure 2. SEM micrograph of sample 5644 both pre and post 80 days natural UV exposure

2.3. Exposure type 3 - Equivalent 80 days artificial UVA and UVB exposure

Table 5. Percentage change in sample characteristics for equivalent 80 days artificial UVA exposure

Sample	Tensile strength	Percentage elongation	Linear density	Colour change
5644	-2.34%	14.97%	2.74%	No change
5646	1.07%	11.61%	-6.67%	No change
5655	-4.52%	8.79%	0.54%	No change
5656	-10.70%	1.12%	3.49%	Lighter

Table 6. Percentage change in sample characteristics for equivalent 80 days artificial UVB exposure

Sample	Tensile strength	Percentage elongation	Linear density	Colour change
5644	-88.13%	-97.49%	16.44%	Lighter
5646	-33.31%	14.36%	29.52%	Lighter
5655	-27.06%	-18.37%	1.26%	Lighter
5656	-25.38%	3.16%	0.47%	Lighter

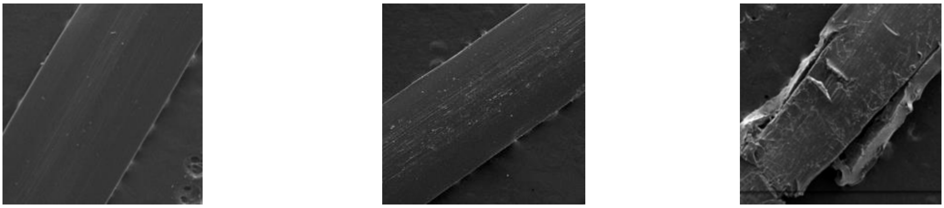

Figure 3. SEM micrograph of sample 5644 both pre and post equivalent 80 day artificial UVA and UVB exposure

3. Data analysis

3.1. Exposure type 1 – Sportslabs Ltd.

Through the various types of exposures investigated, there have been some noteworthy results. Firstly looking at Table 2 it can be seen that all the yarn samples are able to resist significant amounts of sustained UVA exposure, with minimal degradation. Figure 1 shows a SEM image taken both pre and post exposure with little changes seen. Since artificial UVA is more akin to natural UV exposure, it is used by the three sporting bodies to test the suitability of samples for use. Table 7 shows that all the samples would be fit for use as an artificial playing surface for Rugby, Soccer and Field Hockey. The standards (BS EN 14836:2005) require a change in tensile strength of no more than 50% and a grey scale rating of no less than 3 when exposed to UVA.

Table 7. Percentage change in sample characteristics for equivalent 80 days artificial UVA exposure

	Sporting governing bodies					
Sample	**IRB**		**FIFA**		**FIH**	
	Tensile strength	Colour change	Tensile strength	Colour change	Tensile strength	Colour change
5644	Yes	Yes	Yes	Yes	Yes	Yes
5646	Yes	Yes	Yes	Yes	Yes	Yes
5655	Yes	Yes	Yes	Yes	Yes	Yes
5656	Yes	Yes	Yes	Yes	Yes	Yes

Certain results recorded seem irrational. Certain samples increased their percentage elongation and linear density from pre to post UV exposure. Firstly the increase in percentage elongation can be explained through the initial crosslinking experienced during the degradation process actually increasing the elasticity of the material [9] with prolonged crosslinking eventually leading to a loss. The increases in linear density could be caused due to impurities left on the sample surface such as residue of evaporated water etc. as seen in Figure 4.

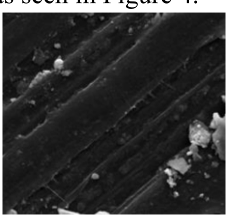

Figure 4. SEM micrograph depicting impurities left on the sample surface

All four samples experienced a loss in colour this would suggest that the colour pigments used in the samples are quite susceptible to erosion. When the samples were handled post UV exposure a sticky residue could be felt which would suggest Gloss loss occurred through the weeping process where the pigment is removed through a chemical reaction leaving a sticky residue.

3.2. Exposure type 2 – 80 days of natural UV exposure

The results recorded in Table 4 show no consistency between all the samples. When one looks at the minimal losses experienced by the samples being exposed to artificial UVA for a substantial amount of time (Table 2) and compares this to the samples being exposed to natural UV, during winter months for substantially less amount of time (Table 4), it allows for the conclusion that no degradation has in fact occurred. This is confirmed by the SEM images in Figure 2 where no change can be seen from pre to post exposure. The increases and losses recorded can be explained by the fact that no one piece of sample is the same. No matter how small the difference it will be detected when measuring such a sensitive material.

3.3. Exposure type 3 - Equivalent 80 days artificial UVA and UVB exposure

The equivalent 80 day artificial UVA once again offered little in terms of degradation which for reasons explained above, is expected. One interesting comparison occurred with the colour change, where both the 80 day natural UV (Table 4) and equivalent 80 day artificial UVA exposures (Table 5) had the same results. The colour change measurement used was however qualitative and therefore subjective, a more quantitative measurement should be used in future for greater accuracy. The similar rates of degradation between the 80 day natural and equivalent 80 day artificial UVA suggest that UVA is the predominant type of UV exposure in Johannesburg in winter.

The equivalent 80 day artificial UVB exposure, offered some fascinating results and showed exactly how artificial turf degrades as well as the process leading to it. Figure 3 shows how sever the degradation is compared to UVA (post UVA is the center image and post UVB is the image on the right). Through the micrographs it was possible to see the crazing and cracking that occurs. The fibrillated samples actually melted and fused together with the monofilament samples snapping and warping due to the intensity of the UVB. Figure 5 shows a magnified image of sample 5644's surface illustrating how voids form and propagate into a crack. These cracks reduce the materials ability to perform as initially intended as seen in the results of Table 6.

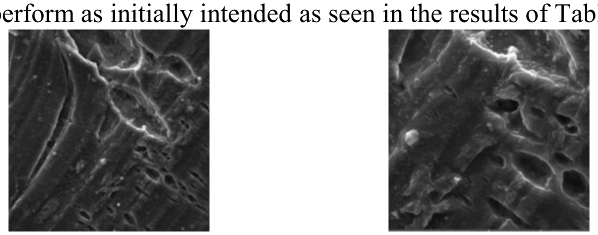

Figure 5. Magnified SEM micrographs depicting cracking on sample 5644's surface

One interesting thing to note is how susceptible the samples were to degradation when exposed to artificial UVB as compared to UVA. Given that their energy and wavelengths are completely different with UVB being the harsher of the two but this would suggest that the UV stabilizers are very much dependent on the type of UV being exposed.

UV stabilizers work much the same as sunscreens applied by humans. Sunscreens either offer UVB (SPF rating) protection or a broad spectrum protection. Broad spectrum protection means the sunscreen protects against both the shorter wavelengths of UVA as well as UVB [2, 12]. This phenomenon is illustrated with the monofilament samples. Sample 5644 suffered degradation with UVA and serve degradation with UVB suggesting a UVA stabilizer was used (Tables 5 and 6). Sample 5646 performed reasonably well against both UVA and UVB (Tables 5 and 6) suggesting a broad spectrum UV stabilizer was used. Sample 5646 was also the only sample to be exposed to artificial UVB for the required time stipulated by the sporting bodies (Table 3) where it performed reasonably well.

4. Conclusions and recommendations

Through this study, it was possible to confirm the degrading effects that UV has on synthetic turf in terms of cracking, crazing and colour change. It was also possible to rate each sample against the standards set out by the sporting governing bodies (IRB, FIFA and FIH). These standards need to be revised, as they only cover UVA exposure, which is sufficient for low UV intensive areas. However synthetic turfs are being installed in UV intensive areas where UVB degradation becomes an issue.

The 80 days of natural UV exposure along with the equivalent 80 days of artificial UVA offered insight into a possible correlation between artificial and natural UV. These exposures confirm work done by Fredor and Brennan where an acceleration factor is highly dependent on location [13]. It is believed that should a full year of natural UV exposure be performed a correlation across all tests may be achieved.

These exposures revealed that the UV stabilizers effectiveness are largely dependent on the type of UV they are designed to resist. Consideration should be taken in terms of which type of UV stabilizer is suitable for the location where the turf will be used. Broad spectrum stabilizers should be used in UV intensive areas with UVA stabilizers in less intensive areas.

UV stabilizers, like sun screen, do not offer a permanent solution to UV degradation as over time they lose their effectiveness. The building of fully enclosed and semi enclosed sporting stadiums in conjunction with the use of UV stabilizers could offer a more permanent solution.

References

[1] Target Technologies International, *Artificial / Synthetic Turf Infill & Materials: A Brief History of Artificial Turf*, Available from: http://www.ttiionline.com/turf_industry_history.htm 7 October 2013

[2] UV Awareness, *What is UV,* Available from: http://www.uvawareness.com/uv-info/uv-information.php, 5 July 2013.

[3] Q-Lab, *Sunlight, Weathering &Light Stability Testing.* Q-Lab, Westlake, Ohio, USA, 2007.

[4] Q-Lab, *Controlled Irradiance in Laboratory Weathering: Limitation in the State of the Art.* Q-Lab, Westlake, Ohio, USA. 1994.

[5] swicoFil, *Vitagrass monofilament yarns,* Available from: http://www.swicofil.com, 5 July, 2013.

[6] Harper, C, *Handbook of Plastics Technologies: The Complete Guide to Properties and Performance: Chapter5 Plastic Additives,* McGraw-Hill Professional, Access Engineering, 2006.

[7] Kitsinelis, S, *Light Sources Technologies and Applications.* Taylor & Francis. 12 materials and technology, 2010.
[8] Vasile, P and Cornelia, M, *Practical guide to polyethylene.* Rapa technology limited. Shawbury, U.K, 2005.
[9] Callister, W, *Materials science and engineering an introduction 7th ed,* United States of America: John Wiley & Sons, Inc. 9 swicofil, 2007.
[10] Materials Technology, *UV Degradation Mechanisms.* Available from: http://www.drb mattech.co.uk /uv%20degradation.html, 16 March 2013.
[11] Heuvel - Folies bvba, *Levensduur (uv-starling).* Available from: http://heuvelfolies.be/CMS/Producten/Tunnel-%20en%20serrefolie/Folie-eigenschappen, 13 July 2013.
[12] American Cancer Society, *Skin cancer prevention and early detection – UV protection. Available from:* http://www.cancer.org/cancer/skincancermelanoma/moreinformation /skin cancerpreventionandearlydetection/skin-cancer-prevention-and-early-detection-u-v-protection, 5 July 2013.
[13] Fedor, G and Brennan, P, *Comparison between Natural Weathering and Fluorescent UV Exposures: UVA-340 Lamp Test Results, Durability Testing of Non-Metallic Materials*, ASTM STP 1294, Robert J. Herling, Ed., American Society for Testing and Material, Philadelphia, 1996.