Factors Impacting Degradation of Artificial Turf Fibers

Kunstgress 2021

A project on artificial turf

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Preface

KG2021 is a three-year project focusing on development and testing of new and sustainable concepts for future artificial turfs. The purpose of the project is based on spread of microplastics and leakage of pollutants due to use of rubber granulates (SBR) from car tires. Pilot fields with artificial grass without granulates are being constructed to reduce pollution and provide reduced lifetime costs.

Trondheim, July 2020

Abstract

The aim of this study is to present an overview over factors that impact degradation of artificial turf fibers, based on previous research on the topic. The report is written in collaboration with Centre for Sport Facilities and Technology (SIAT) at the Norwegian University of Technology and Science (NTNU) and the project Kunstgress 2021 (KG2021). The project focuses on the development and testing of new concepts for future artificial turfs.

It is found several factors that may lead to both mechanical and chemical degradation of artificial turf fibers. These include degradation from poor maintenance and increased number of usage hours in addition to degradation from UV radiation and alterations in surface temperature. These lead to potential changes in the properties of the artificial turf fibers. The most damaging cause leading to degradation of fibers is believed to be UV radiation with additional surface heating. Preventive measures can be done to minimize degradation of the grass fibers thus keeping aesthetics and playing abilities, in addition to ensure longevity. Measures includes use of proper maintenance equipment and sub terrain heating during winter, spread activity (recreational sports) around the pitch, and removing contaminants from the pitch. Irrigating the turf with coolants such as water may for a period lower the surface temperature, preventing unnecessary damage from usage during sunny days.

Previous research is heavily focused on mapping changes in the properties of the fiber after exposure in an accelerated environment. Effect of UV radiation seem to be the most researched topic. Upon transferring knowledge from laboratory testing to an actual football field, multiple additional parameters must be considered. Some of these include field age, type and quantity of infill material, and field location. Results from accelerated tests may therefore be considered as worst-case scenario in terms of degradation of fibers. No previous research on the long-term effect of degradation was found. Measuring mass loss from wear over time in different environmental conditions temperature, UV), could be done to achieve better understanding of the process behind degradation caused by maintenance and sport’s activities.

Sammendrag

Hensikten med rapporten er å presentere en oversikt over ulike faktorer som kan bidra til degradering av kunstgressfiber, basert på tidligere forskning. Rapporten er skrevet i samarbeid med Senter for idrettsanlegg og teknologi (SIAT) for prosjektet Kunstgress 2021 ved Norges teknisk- naturvitenskapelige universitet (NTNU) i Trondheim. Prosjektet setter søkelys på utvikling og testing av nye konsepter for fremtidens kunstgressbaner.

Det ble funnet flere faktorer som fører til både mekanisk og kjemisk degradering av kunstgressfiber. Disse inkluderer degradering fra manglende og dårlig vedlikehold og økt antall brukstimer i tillegg til degradering fra UV-stråling og endringer i overflatetemperatur. Faktorene fører til mulige endringer i fibrenes egenskaper. Den mest ødeleggende faktoren som fører til degradering av fiber er trolig UV-stråling med tilhørende oppvarming av kunstgressets overflate. Preventive tiltak kan gjøres for å minimere degradering og sørge for at banen beholder sin estetikk samt sikrer gode spillegenskaper og lang levetid. Tiltak inkluderer bruk av anbefalt utstyr til vedlikehold, bruk av undervarme om vinteren, utnyttelse av hele banen ved fritidsbruk og fjerning av uønskede gjenstander. Vanning av kunstgressmatten kan over en periode bidra til redusert overflatetemperatur, og forhindre unødvendig skade ved bruk av banen på solfylte dager.

Fokusområdet for tidligere forskning har vært kartlegging av fiberet sine egenskaper etter eksponering i akselererte tester. Effekt av UV-stråling ser ut til å være det som er mest undersøkt. Ved overføring av kunnskap fra laboratorietester til en utendørs fotballbane må flere parametere tas i betraktning. Noen av disse er alderen til banen, type og mengde ifyllsmateriale og banelokasjon. Resultater fra akselererte tester kan derfor anses som verst tenkelig scenario med tanke på degradering av fiber. Ingen tidligere forskning viser den langsiktige effekten av degradering. Måling av massetap over tid i ulike klimatiske forhold med varierende temperatur og UV kan gjøres for å få dypere innsikt om degradering forårsaket av vedlikehold og bruk.

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Introduction

Artificial turf is a popular choice when a new football field is planned to be built, especially in countries where stable conditions of the turf is desired independent of weather conditions. Installing artificial turf instead of natural grass makes the field available for use all year around, even during the winter. Less maintenance is also required on an artificial field to achieve optimal playing abilities continually throughout the year compared to natural grass [1].

The hot topic within the artificial turf community is the concern about loss of infill material (granules) which leads to leakage of microplastics to the environment [2], [3]. Development and testing of new concepts for artificial turfs are therefore ongoing, where alternative infill materials are being tested. In addition, installing turfs without the need for infill material are investigated, where a double layer of fibers may substitute the properties of the infill material. If the latter option becomes reality, microplastic leakage from infill will no longer be an issue. Attention may therefore be aimed towards other components such as the artificial turf fiber, which also has the potential to harm the environment due to emission of microplastics [4]. Because fibers are tufted into the backing on artificial turf, strong physical force is required to loosen them. However, both mechanical and chemical degradation will occur within the material and are unavoidable. The fibers may for example degrade due to impact from UV radiation, temperature changes and poor maintenance [5], [6]. Figure 1 show piling of fiber on maintenance equipment [7].

Figure 1: Loose fibers piled up on maintenance equipment. Photo by Bjørn Aas.

In addition to potential emission of microplastics, degradation or removal of fibers lead to uneven playing abilities in terms of ball roll and bounce [8]. To maintain field characteristics, frequent maintenance is needed. If not done properly, maintenance may cause increased degradation [1]. The undesirable result of poor degradation is reduced lifetime of the field and applying unnecessary load to other components such as the backing. The aim of this study is to give an overview over factors that may contribute to degradation of artificial turf fibers. Discussion around the issue is based on available previous research results and principles of polymer science from a materials technology perspective.

Contributing factors to degradation of artificial turf fibers

A flow chart of the different factors that may contribute to degradation of artificial fibers are shown in Figure 2. The chart is divided into two main categories: mechanical- and chemical degradation. Mechanical degradation is damage to a material caused by physical contact with another. Chemical degradation includes breaking chemical bonds within the material without physical interaction [9]. Mechanical degradation focuses on the effect of maintenance on an artificial field, both regular maintenance that must be done all year round, and maintenance during the winter season such as ice and snow removal. Mechanical degradation from use includes wear due to physical interaction between the turf and football shoes. The other main category covers natural causes that degrade the fibers chemically. These factors include UV radiation in addition to alterations in surface temperature due to climatic conditions such as cold weather. The temperature limits "high" and "low" are determined from summer and winter season, where temperatures under 0 °C present problems due to freezing of water on the surface.

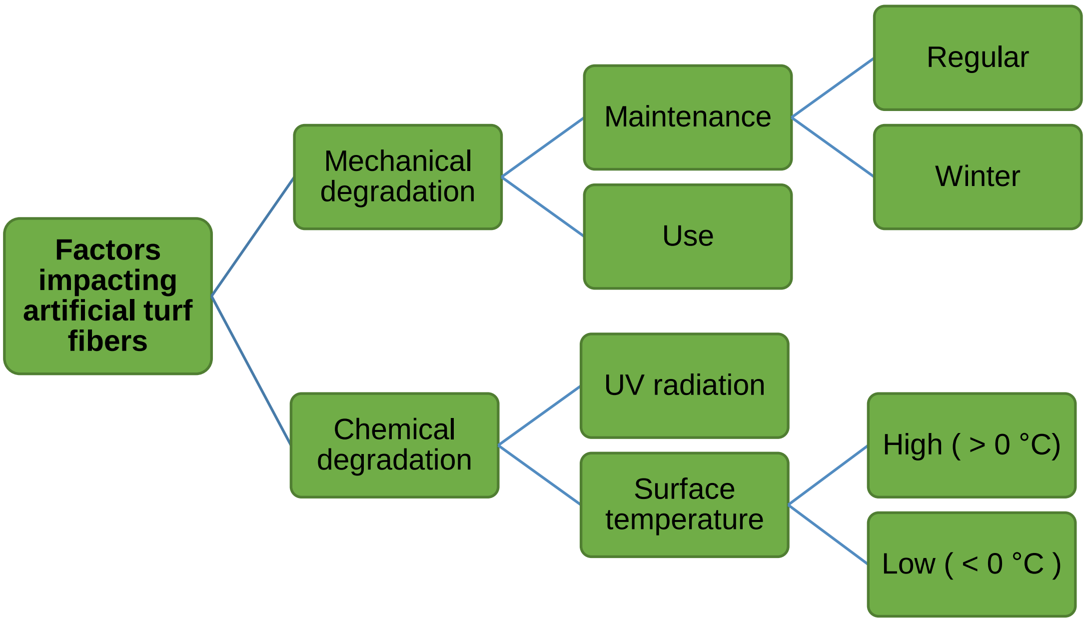

Figure 2: The different factors that contribute to degradation of artificial turf fibers.

Mechanical degradation of artificial turf fibers

Mechanical degradation occurs when external substances physically interfere with the fibers, and mass is either moved or removed from the material's surface [10]. Different types of wear mechanisms such as abrasive- and adhesive wear forms the basis of degradation. The degree of degradation that might occur depends on the physical and mechanical properties of the fiber. The following sections describes factors that degrade the artificial turf fibers mechanically, with emphasis on maintenance. Research as to what degree insufficient regular maintenance affects degradation is yet to be found. Fleming [10, p. 50] describes that "*The degradation mechanism(s) of artificial turf wear and the effectiveness of maintenance practice are currently poorly understood and underresearched*". Although, it is led to believe that lack of regular maintenance in combination with increased number of usage hours contributes to degradation of fibers over time.

Regular maintenance

Regular maintenance on an artificial field is crucial to maintaining playing abilities such as even ball roll and bounce, grip, and shock absorption. Proper maintenance is a key factor in terms of keeping aesthetics, safety, and ensure longevity of the field. It is also stated by FIFA [8], that "Correct maintenance will significantly influence the return on investment from your pitch". In Norway, general instructions on how to maintain an artificial turf is described in *Kunstgressboka* [1]. Maintenance practices for a specific field is described in the operation and maintenance manual (O&M manual), provided by the supplier. The document describes how, when and how often maintenance should be done, as well as equipment requirements [11]. Regular maintenance includes refilling infill, levelling the infill, rising the fibers by brushing, as well as removing potential contaminants in the turf. Other maintenance tasks include checking of seams, decompaction of infill in high-use areas and removal of weeds [8].

Degradation during regular maintenance

When levelling the infill by dragging the brush with a tractor unit, it is important for the operators to be aware of the importance of keeping a speed equal to or below the recommended speed specified in the operation and maintenance manual (usually 5 km/h, 3 mph). When the fibers are subject to higher strain rates, the material will experience degradation either from increased elongation or even breakage if the speed is high enough. Speed is especially important at colder temperatures, due to the fibers more brittle behavior making them more vulnerable to breaking [12].

Clogging of infill can easily occur on the brushes [8]. Making sure that the bristles are free ensures that the brush also reaches the lower part of the fibers, removing potential contaminants that have been piled up. Potentially, a well-used brush will only engage the upper part of the turf, and not serve its purpose as infill-leveler and fiber-upriser. Degradation may therefore more easily occur as the fibers retain flat and the infill is not getting evenly distributed. In zones with less amount of infill, a greater proportion of the fiber will be exposed to other factors that contribute to increased degradation, such as UV radiation. Refilling infill is therefore necessary to avoid such damage.

Winter maintenance

Winter maintenance must be done to accommodate the demands of maintaining optimal playing abilities and qualities during the winter. This applies mostly to countries in the northern hemisphere, especially Scandinavian countries. From an economic perspective, winter maintenance can be a challenging task due to the cost of proper equipment and use of undersoil heating. The latter should only be done by trained personnel. Maintenance during winter include mechanical removal of snow and ice from plowing and milling, controlling undersoil temperature, and optionally adding de-icing agents (salts) [1].

Degradation during winter maintenance

During snow plowing, plow blades should not be touching the turf [8]. Interaction between the potentially sharp blade and the fibers can cause unnecessary damage which can be avoided. Installing an elastomer pad on the blade is therefore favorable for protecting the turf during snow removal due to its softness. Maintaining fields without a heating system is especially difficult due to the formation of ice. Immediate removal of ice is therefore important to ensure proper drainage and prevent increased degradation from additional sharp ice pieces when removing snow. For non-heated fields, use of de-icing agents in combination with plowing and milling seems to be the most viable solution, as described in [1]. Speed should be higher than during regular maintenance (15 - 18 km/h), ensuring that snow is being rolled instead of pushed by the plow blades shown in Figure 3. This will prevent damage from straining the fibers [13].

Figure 3: Rolling the snow during snow removal prevents damage to the fibers [13].

Salts and acetates, either in solution or as pure solids, are mostly used as a preventive measure to avoid formation of ice on artificial turf. De-icing agents can also be used to melt ice that already have been formed. The most common types are sodium-, magnesium- and calciumchloride, where the first is preferred over the others [11]. In addition, calcium acetate (CMA) may also be used [15]. According to the salts safety data sheets, none of the above is described to have destructive effect on polymeric materials [14] - [15]. No study shows the effect salt or other de-icers upon degradation of artificial turf's components. A potential risk might be crystallization of salt when the temperature rises. This can block drainage.

Degradation from use

Degradation of the fibers from use is unavoidable due to physical interaction between the turf and football studs under the shoes of the players. Surrounding factors such as climatic conditions (wet, dry, hot, cold) lays the foundation for what type, and to what degree degradation occur during use. In high-use areas (especially near the field entrance, in the penalty area and at corners flags) the turf will experience increased degradation due to disruption of infill [8]. Location of the field, for example near a school facility, may also contribute to more use in certain parts of the field. Taking advantage of the whole pitch is believed to be important to prevent severe damage to these high-use areas. Activities may therefore be moved to areas that are far away from the entrance, and football in the recreational sphere should be performed in low-use areas [16]. This way damage will be spread more evenly around the turf, saving the most vulnerable areas.

Chemical degradation of artificial turf fibers

Chemical degradation of fibers include weakening, restructuring, or even breaking chemical bonds in the material structure. The main reason behind chemical degradation is absorption of solar energy. Factors that degrade the fibers chemically therefore focuses on UV radiation and changes in surface temperature of the field due to weather conditions.

UV radiation

UV radiation is described as the most devastating factor for polymers and can be divided into three categories: UVA, UVB and UVC [12]. The UV radiation reaching the surface of the Earth is composed of UVA and a small amount of UVB [17]. Sunrays penetrates the material's surface and break bonds between the molecules in the polymer chains, causing potential loss of mechanical properties. UV stabilizing agents are therefore added to the artificial turf fiber blend to ensure resistance against UV degradation. Nevertheless, the added UV stabilizer is confidential from producers, where parameters such as composition and quantity vary. Artificial UV can be used to simulate natural outdoor conditions, and the damaging effect of UV radiation can be measured by examining changes in the fiber's properties after exposure. The following sections presents results from previous research upon UV exposure of polymer fibers and films.

Degradation from UV radiation

A study performed at Israel Institute of Technology shows the effect on tensile properties on thermoplastic and crosslinked low-density polyethylene (LDPE) due to artificial UV radiation [18]. The LDPE blend were added various amounts of crosslinking agent as well as 1 % UV stabilizer. Changes in elongation, strength and stiffness were noted after UV exposure for 250, 500, 700 and 100 hours. Changes in all tensile properties can be seen for every test series with increased exposure times. Non-stabilized fibers experienced greatest change, with loss of strength and reduced elongation of the fibers. The effect of UV stabilizer was prominent, where minimal changes due to exposure were measured for the UV stabilized test series.

Low-Density Polyethylene (LDPE) was exposed to UV radiation under four environmental conditions; two salt solutions with ionic strengths of 0.017 M (drinking water) and 0.6 M (seawater), double distilled water (DDW) and air [19]. All test samples were exposed at 30 °C. Changes in physical, chemical, and mechanical properties were evaluated after 30, 60, and 90 days of exposure. The study found that UV exposure in air and distilled water degraded the fibers to a greater extent than the two salt solutions. The study also shows that increased ionic strength offers better protection of LDPE from UV radiation, as exposure in 0.6 M saline water only lead to a slight change in tensile properties.

Producers of artificial turf does also measure the effect of UV radiation on their specific products. A presentation made by FieldTurf in collaboration with producer Morton Extrusionstechnik GmbH presents information on their artificial turf [20]. Cross-tenacity testing of fibers after artificial UV exposure were performed, and the results were compared with fibers from a competing manufacturer. What separates the two is the amount of UV stabilizer added, where Fieldturf's fibers are protected with 10 mg/g and the competitor with 6 mg/g. Figure 4 shows the results from the testing where change in tenacity [%] is shown on the y axis and time in UV chamber [h] on the x axis. It is shown that Fieldturf fibers with 10 mg/g (green rectangle) maintained 85 % tenacity after 10,000 hours of aging, and the opposer with 6 mg/g (blue rectangle) lost 50 % tenacity after 3000 hours. Both fibers have sufficient UV stabilization according to FIFA's specifications [21]. The report does not mention anything about composition of the UV stabilizers, and it is noted that two different standards are used for UV exposure.

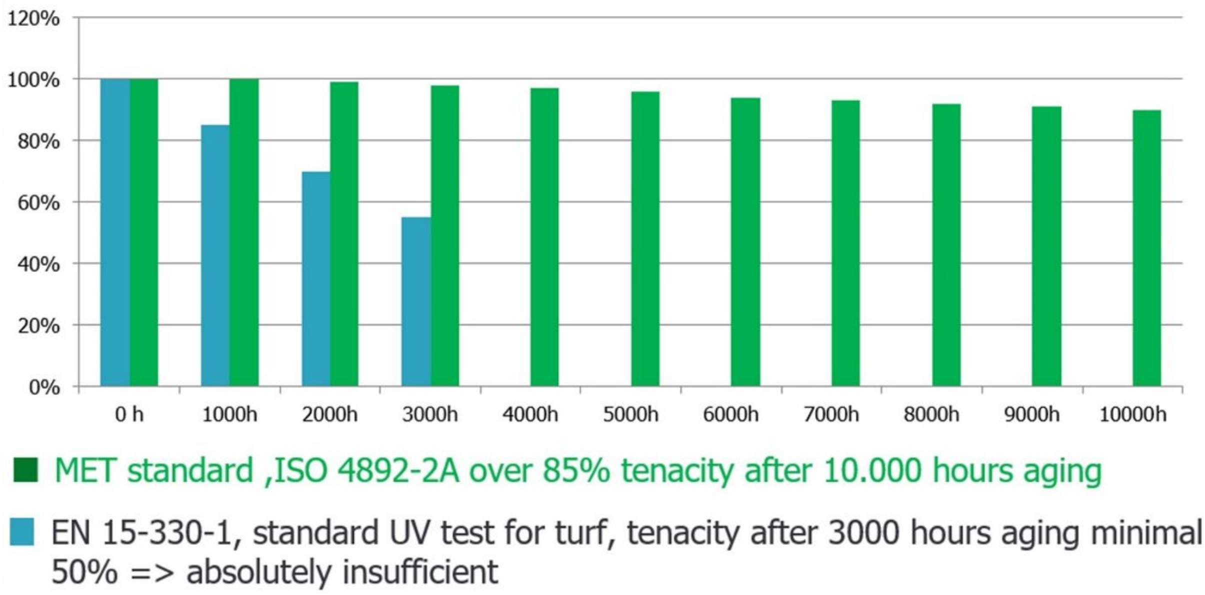

Figure 4: Change in tenacity [%] for two different turfs after 10 000 hours of UV exposure. Fieldturf fibers with 10 mg/g (green rectangle) maintained 85 % tenacity after 10,000 hours of aging, and the competitor with 6 mg/g (blue rectangle) lost 50 % tenacity after 3000 hours. Source: Adapted from [20].

Turf installed in UV intensive areas also need appropriate UV stabilizing agents to prevent degradation. This means protection both against UVA and UVB radiation. The effect of these two types of UV was mapped by comparing loss of mechanical properties and color change in a study conducted in Johannesburg, South Africa [22]. Four different artificial turf fibers were exposed for 80 days in UVA and UVB chambers. The fibers were provided by Sportslabs Ltd. From the results, drastic effect of UVB exposure compared to UVA could be seen, especially in loss of strength. UVB irradiated samples also seemed lighter in color after exposure.

Based on previous research, impact of UV radiation seems to be well described and understood. Trends are highly visible, where increased exposure times without exception lead to increased degradation. UVB also seem to be the most damaging type of UV radiation, thus only small portions reach the earth’s surface. Transferring knowledge from laboratory tests to an actual outdoor artificial turf is nevertheless difficult.

The test standard ISO 4892-2:2013: “Plastics - Methods of exposure to laboratory light sources - Part 1: General guidance” supports this by the stating that:

> *Relating results from accelerated weathering or artificial accelerated irradiation exposures to those obtained in actual-use conditions is difficult because of variability in both types of exposure and because laboratory tests never reproduce exactly all the exposure stresses experienced by plastics exposed in actual-use conditions. No single laboratory exposure test can be specified as a total simulation of actual-use exposures* [23, p. V].

High surface temperature (> 0 °C)

Alterations in surface temperature also lead to changes in the properties of the artificial fiber. Solar radiant energy is the main source for the temperature changes, and other factors as rain, snow, and wind also effect how hot or cold the surface gets. The most recognizable effect of temperature changes is altered playing abilities because of chemical degradation of the turf’s components. Research regarding which effect alternating temperature has upon degradation of turf fibers are unfortunately limited.

A study from Brigham Young University in Boston, USA, investigated the range of temperatures over time on a pitch delivered by Field Turf field [24]. The study indicates that the average temperature of the artificial field was approximately 22 °C higher than natural grass. The artificial turf field also reached temperatures of maximum 90 °C with the air temperature only at 37 °C. The reason for this is heat absorption not only in the fibers, but also the infill and the areas around the field. Heat transfer between the components is thus likely to play a role in terms of heating of the artificial turf. Increased temperature may lead to expansion in the structure of the fiber, where small particles may enter. Loss in strength as well as increased elongation may therefore occur, meaning less force is required to damage the material. Irrigation can be a viable option to lower the surface temperature, as shown in a study performed at the Pennsylvania State University [25]. Surface temperatures were lowered by 34 °C within 15 minutes of irrigation and remained stable at around 37 °C for the remaining 210 minutes. No information on temperature of the water applied was recorded.

Low surface temperature (< 0 °C)

In other direction of the temperature scale, surface temperatures below 0 °C (freezing point of water) will make the fibers stiffer and have more brittle behavior [26]. Applying a force to the brittle fibers will most likely cause them to break, as opposed elongation of the fibers which happens during high temperature deformation. If the temperature reaches below the freezing point of water, seams in the turf can be displaced due to expansion as the water in these areas freezes. Maintaining the artificial turf during winter should be done with proper equipment, following instructions from the supplier of the field.

Conclusion

The study points at natural and inflicted factors that contribute to degradation of artificial turf fibers. It can be concluded that both mechanical and chemical degradation is unfavorable due to change in fibers properties. Preventive measures can be done to minimize degradation thus keeping aesthetics and playing abilities, in addition to ensure longevity. Measures include use of proper maintenance equipment and undersoil heating during winter, spread activity (recreational sports) around the pitch, and removing contaminants. The most damaging factor that lead to degradation of fibers is believed to be UV radiation with additional surface heating. Irrigating the turf with coolants such as water may for a period lower the surface temperature, preventing unnecessary damage from usage during sunny days.

Previous research on artificial turf fibers have focused on mapping changes in fiber properties after exposure in an accelerated environment. Effect of UV radiation seem to be the most researched topic. When transferring knowledge from laboratory testing to an actual football field, multiple additional parameters must be included. Some of these include field age, type and quantity of infill material, and field location. Results from accelerated tests may therefore be considered as worst-case scenario in terms of degradation of fibers. No research on the long-term effect of degradation was to be found. Measuring mass loss from wear over time in different environmental conditions (temperature, UV), could potentially be done to achieve better understanding of the process of degradation caused by from maintenance and sport’s activities.

References

[1] Kulturdepartementet, "Veileder V-0975 B: Kunstgresshåndboka," Kulturdepartementet, Oslo, 2015.

[2] European Chemicals Agency, "ECHA proposes to restrict intentionally added microplastics," 19 Mars 2019. [Online]. Available: https://echa.europa.eu/-/echa-proposes-to-restrict-intentionally-added-microplastics. [Accessed 09 Februar 2020].

[3] Miljødirektoratet, "Innhenting av supplerende informasjon om løs plastbasert innfyllsmateriale," Norconsult, 29 Mai 2018. [Online]. Available: https://tema.miljodirektoratet.no/Global/dokumenter/horinger/Industri/Norconsult.pdf?epslanguage=no. [Accessed 09 Februar 2020].

[4] Mepex, P. Sundt, F. Syversen, O. Skogesal and P.-E. Schulze, *Primary microplastic-pollution: Measures and reduction potentials in Norway,* Oslo: Miljødirektoratet, 2016, pp. 91-92.

[5] W. L. Hawkins, Polymer Degradation and Stabilization, Berlin: Springer-Verlag, 1984, pp. 3-34.

[6] Z. Matusinovic and C. A. Wilkie, Polymer Blends Handbook, Polymer Blends Handbook, Volume 2, 2014, pp. 1385-1430.

[7] Senter for Idrettsanlegg og Teknologi, "Hva skjer med fiberet?," Senter for Idrettsanlegg og Teknologi, Trondheim, 2020.

[8] Fédération Internationale de Football Association, *FIFA Quality Programme for Football Turf,* Zurich: FIFA, 2015.

[9] R. M. Christensen, "Interactive Mechanical And Chemical Degradation In Organic Materials," Pergamon Press Ltd, Livermore, 1983.

[10] M. J. Neale, *Lubrication and Reliahability Handbook,* Woburn: Butterworth-Heinemann, 2001.

[11] FieldTurf, "Maintenance Guidelines," FieldTurf, Montreal, 2017.

[12] A. B. Strong, Plastics Materials and Processing, 3. ed., Upper Saddle River, New Yersey: Pearson Education, Inc., 2006.

[13] Norges Fotballforbund, "Vinterdrift av kunstgressbanen - i et helse- og miljøperspektiv," Norgen fotballforbund, Oslo, 2018.

[14] KPT Komet A/S, "Sikkerhetsdatablad Magnesiumklorid," 06 Juni 2011. [Online]. Available:

https://app.ecoonline.com//documents/msds/1011291/285_5711243.pdf. [Accessed 22 Juni 2020].

[15] VWR, "Sikkerhetsbrosjyre Kalsiumklorid," 24 October 2012. [Online]. Available: https://app.ecoonline.com//documents/msds/1000472/285_8487252.pdf. [Accessed 22 Juni 2020].

[16] Synthetic Turf Council, "Guidelines for Maintenance of Infilled Synthetic Turf Sports Fields," Januar 2013. [Online]. Available: https://cdn.ymaws.com/www.syntheticturfcouncil.org/resource/resmgr/guidelines/STC_Guidelines_for_Maintenan.pdf. [Accessed 22 Juni 2020].

[17] International Programme On Chemical Safety, "Ultraviolet radiation," World Health Organization, Geneva, 1994.

[18] J. Miltz and M. Narkis, "The Effect of Ultraviolet Radiation on Chemically Crosslinked Low-Density Polyethylene," Journal of applied polymer science, Israel, 1976.

[19] V. P. Ranjan and S. Goel, "Degradation of Low-Density Polyethylene Film Exposed to UV Radiation in Four Environments," Journal of Hazardous, Toxic and Radioactive Waste, West Bengal, 2019.

[20] J. Morton, "Morton Extrusionstechnik," FieldTurf, Abtsteinach, 2017.

[21] European Committee for Standardization, "DIN EN 15330-1 - Spesification for synthetic turf surfaces for football, hockey, rugby union traing, tennis and multi-sports use," European Committee For Standardization, Brussel, 2013.

[22] A. C. Zuzarte and D. Kruger, "The effects of natural and artificial UV exposure on the physical properties of synthetic turf used for various sports fields," in *Construction Materials and Structures*, Johannesburg, IOS Press, 2014, pp. 1453 - 1460.

[23] International Organization for Standardization, "ISO 4892-2:2013: Plastics - Methods of exposure to laboratory light sources - Part 2: Xenon-arc lamps," ISO, Geneva, 2013.

[24] C. F. Williams and G. E. Pulley, "Synthetic Surface Heat Studies," Brigham Young University, Brigham, 2002.

[25] A. S. McNitt, "Evaluation of Playing Surface Characteristics of Various In-FIlled Systems," Pennsylvania State Universtiy, State College, 2016.

[26] D. Whisnant, *Polymer Chemistry: The Glass Transition,* Spartanburg, Sør-Carolina: Engineering LibreTexts, 2020.

[27] P. Fleming, "Artificial Turf Systems for Sport Surfaces: Current Knowledge and Research Needs," Journal of Sports Engineering and Technology, Loughborough, 2010.

[28] KPT Komet A/S, "Sikkerhetsdatablad Natriumklorid," 14 Mars 2014. [Online]. Available: https://app.ecoonline.com/ecosuite/applic/sk/index.php?applicationID=4&locationID=0#234200. [Accessed 22 Juni 2020].

Available literature

The following table presents literature that was found on degradation of artificial turf fibers.

Table 1: Overview of available literature used in the report.

Study (Author, year, title)	Aim/method	Findings	Comments
Zuzarte, A. C. & Kruger, D. 2014. «The Effects of Natural and Artificial UV Exposure On The Physical Properties of Synthetic Turf Used for Various Sports Fields".	UVA and UVB exposure of four different synthetic yarns for 80 days.	Loss of strength, increased elongation, color change.	No information on UV stabilizing agents.
Miltz, J. & Narkis, M. 1976. "The Effect of Ultraviolet Radiation on Chemically Crosslinked Low-Density Polyethylene".	UV exposure on LDPE films with and without 1 % UV stabilizer	Loss of strength and reduced elongation for unstabilized LDPE. Little to no effect on UV stabilized LDPE	No information on radiant intensity from UV lamp.

Ranja, V. P & Sudha, G. 2019. «Degradation of Low-Density Polyethylene Film Exposed to UV Radiation in Four Environments".	UV exposure of LDPE strips in air, double distilled water (DDW), and two salt solutions (0.017 M and 0.6 M).	Greatest changes in mechanical properties of LDPE in air, followed by DDW, in 0.017 M and least of all in 0.6 M. Formation of salt crystals in saltine solution (0.6 M).	
Williams, C. Frank & Pulley, G. E. 2002. "Synthetic Surface Heat Studies".	Temperature measures over time on synthetic turf.	Synthetic turf reached maximum 90 °C with air temperature at 37 °C. Synthetic turf also much warmer than natural turf.	
Mcnitt, A. S. 2016. "Evaluation of Playing Surface Characteristics of Various In-Filled Systems".	Effect of irrigation on temperature on artificial turf	Surface temperature lowered by 34 °C within 15 minutes of irrigation. Steady increase in surface temperature after 15 minutes.	No information on water temperature upon irrigation.