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Performance artificial turf components – fibrillated tape

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Abstract

Artificial turf surfaces with “soft” yarns are increasingly used because of haptic attractiveness and player friendliness. Linear low density polyethylene (LLDPE) with low density is preferred to achieve the desired softness. The choice of LLDPE material is guided by the performance requirements outlined in the FIFA Quality Concept for football turf [1]. Different LLDPE materials were extruded into fibrillated tape yarns on pilot and production scale machinery. A key mechanical property of fibrillated yarns is the tear resistance in machine direction influencing the fibrillation process and the ultimate yarn splitting and resulting wear in the field. A high tear resistance makes fibrillating the yarn difficult however improves the ultimate split and wear resistance in the field. Unfibrillated oriented yarns of different composition were analyzed for tear and other mechanical properties. The results are related to previous work on durability of certain yarn compositions which demonstrate the benefits of low density LLDPE resins in terms of durability and wear resistance [2]. As proof of concept one metallocene LLDPE resin with one of the highest tear resistance values currently commercially available was extruded into oriented yarn and subsequently fibrillated. Processing conditions and choice of particular LLDPE greatly influence yarn fibrillation and performance. As already demonstrated in monofilament yarns [2], shrinkage is identified as an important measure to characterize residual stress in low density LLDPE yarns. We discuss strategies to minimize shrinkage for fibrillated tape made with low density LLDPE and refer to its relation to performance in the Lisport test used to determine the durability of an artificial turf yarn.

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1. Introduction

Today’s ‘third generation’ artificial turf sport surfaces are of high and continuously improving quality. The speed and growth rate of the industry and technology innovation especially for football (soccer) pitches over the last 40 years is indeed impressive [3]. Many aspects of the game played on artificial turf have improved significantly over the years. Today, medical studies show that injuries players experience on natural versus artificial turf show no significant differences in frequency or gravity, except for differences in the body parts involved [4]. FIFA published documentation on technical aspects of the game and player performance evaluating natural versus artificial turf [5].

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By introducing the FIFA Quality Concept [1] with FIFA one and two star certification granted to individual installed pitches, FIFA improves the quality of the game for players around the globe. Latest generation artificial turf constructions with very reproducible playing conditions have by now made significant inroads into American Football, Soccer, Rugby and other major sports, long played on natural turf. In addition, benefits of artificial turf systems include reduced maintenance and water (fertilizer) requirements, higher utilization (more playing hours), rendering the transition to artificial turf economically interesting.

Various polymers are used in the different parts of the artificial turf construction [5]. Consequently, a high quality artificial turf pitch is a complex multicomponent system with fine-tuned properties. Polyethylene (PE) and especially linear-low density polyethylene (LLDPE) has become the raw material choice for the grass blades in the ‘third generation’ pitches. LLDPE based yarn offers reduced skin abrasion and superior player friendliness in sliding and tackling compared to other yarn raw materials, in combination with changes in the construction of the pitch. In the latest installations, longer piles with an elastic infill and a shock absorbent system are used to provide improved player safety and comfort.

In this paper we present developments in fibrillated yarn technology for artificial turf. The most important performance requirements for fibrillated tape are durability (wear, split and degradation resistance), resiliency (repeated elastic recovery of yarn after bending) and softness (player friendliness). The relation between fibrillated tape technology, material science of LLDPE and tear resistance in machine direction is demonstrated. We continue to describe mechanical properties of different LLDPE formulations extruded into oriented tapes. Subsequently, the importance of the process technology transforming a selected LLDPE with high tear resistance into high performance yarn is discussed.

2. Fibrillated yarn technology and tear and wear resistance

Fibrillated artificial turf yarn is produced by extruding a flat cast film into a water bath (or onto a chill roll) for cooling. The film is then tensioned between soft rolls and dried before it is cut into several tapes. In line, temperature controlled rolls tension the tapes further before they enter the stretching oven. Temperature controlled rolls behind the oven run at higher velocity and therefore stretch the tape. The fibrillator, consisting of a roll covered with sets of needles and two further rolls used to press the tape onto this needle roll at a specified angle, is typically installed in between the first high velocity rolls behind the oven and another set of temperature controlled rolls [6].

The tapes enter at high velocity and the needle roll, at higher rotational speed, cuts longitudinal slits in a pattern into the tapes to give them the shape of grass blades. An important point at this processing step is that the needles can actually cut into the tape to split it in longitudinal (machine) direction. In order to cut the tape the needle needs to overcome the material’s tear resistance in machine direction. Consequently, a lower tear resistance will make cutting slits into the tape easier. Several further sets of temperature controlled rolls or heated ovens are used to anneal the fibrillated tape before it is collected on bobbins. From the bobbins the yarn is tufted and fixated into a carpet.

Once the carpet with fibrillated tape is installed in an artificial turf pitch, the low tear resistance that allowed fibrillating the tape has now a negative impact on the wear and split resistance of the yarn. The yarn splits further into finer and finer fibrils. The aim is therefore to balance opposing needs: a sufficiently low tear resistance to allow fibrillation and on the other hand a high tear resistance to prevent so-called post-fibrillation (splitting) in the field.

Tear resistance of LLDPE has been widely studied in blown and cast films [7]. LLDPE is a copolymer of ethylene with a comonomer, the length of which determines to some degree its mechanical properties. The tear resistance of LLDPE has been shown to improve significantly with the length of the comonomer when comparing butene with octene comonomers [7]. We have discussed the importance of tear resistance and other material properties of LLDPE with different comonomer type when extruded into monofilaments in refs [2, 8]. In the density range of 0.910 to 0.923 g/cc LLDPE resins have the highest tear resistance. This is due to a peak in “tie-chain” concentration in this density range – these tie-chains are connecting the crystalline regions of the polymer across the amorphous phase providing resistance to tear propagation. Molecular orientation induced into cast film by stretching either the melt off the die or the solidified film in the oven in machine direction is known to reduce the tear resistance. Fibrillated tape yarn has often been made from high density polyethylene (HDPE) or LLDPE with density above 0.930 g/cc which is higher than the densities where LLDPE has its maximum tear resistance.

In the following we present experiments which demonstrate the dependence of tear resistance (in machine direction) on the choice of LLDPE resin, in particular its density and processing parameters like the stretching ratio.
The LLDPE resins used in the experiments to be explained below are shown in Table 1 and cover a range of densities, melt indices and catalyst technologies.

Table 1. LLDPE and Elastomer resins used in the experiments.

| Nr | Resins       | Catalyst                | Comonomer          | Melt index [g/10min@2.16kg+190ºC] | Density [g/cc] |
|----|--------------|-------------------------|--------------------|-----------------------------------|---------------|
| 1  | LLDPE        | Ziegler-Natta           | Ethylene-Octene    | 2.55                              | 0.935         |
| 2  | LLDPE        | Ziegler-Natta           | Ethylene-Octene    | 2.3                               | 0.917         |
| 3  | LLDPE        | Ziegler-Natta           | Ethylene-Hexene    | 2.3                               | 0.918         |
| 4  | LLDPE        | Ziegler-Natta           | Ethylene-Octene    | 1                                 | 0.905         |
| 5  | LLDPE        | Metallocene             | Ethylene-Octene    | 4                                 | 0.916         |
| 6  | LLDPE        | Metallocene             | Ethylene-Hexene    | 3.5                               | 0.918         |
| 7  | LLDPE        | Ziegler-Natta           | Ethylene-Hexene    | 0.9                               | 0.918         |
| 8  | LLDPE        | Ziegler-Natta           | Ethylene-Butene    | 2.8                               | 0.918         |
| 9  | LLDPE        | Ziegler-Natta           | Ethylene-Butene    | 2                                 | 0.918         |
| 10 | PE-Elastomer | Metallocene             | Ethylene-Octene    | 1                                 | 0.909         |
| 11 | PE-Elastomer | Metallocene             | Ethylene-Octene    | 1                                 | 0.870         |

The resins were extruded into cast films on different lines: a small laboratory scale cast extrusion line, a semi-industrial scale cast line (both with chill roll film cooling) and several different cast film artificial grass lines with water bath cooling as described above. Some of the films were collected directly after quenching without stretching them and others after stretching to a certain draw ratio. Typical ranges of various operating parameters and key resin properties used for the production of fibrillated yarn are shown in Table 2.

Table 2. Parameters of standard fibrillated tape lines. LLDPE – Ziegler-Natta catalyzed Linear Low Density Polyethylene; mLLDPE – metallocene catalyzed Linear Low Density Polyethylene; MDPE – Medium Density Polyethylene; PP – Polypropylene.

| Parameter                          | Options / typical ranges | Units                  |
|------------------------------------|--------------------------|------------------------|
| Resin type                         | LLDPE, mLLDPE, MDPE, PP  |                        |
| Resin density (PE)                 | 0.850 – 0.940 g/cc       |                        |
| Resin melt index                   | 0.5 – 5 g/10min [2.16kg; 190ºC] |                        |
| Extruder output                    | 50 – 450 kg/h            |                        |
| Draw down ratio                    | 1 – 5 Film velocity / melt velocity |                        |
| Line speed (fibrillated tape=FT)   | 30 – 250 m/min           |                        |
| Speed of fibrillator roll          | 100 – 600 m/min          |                        |
| Yarn stretching ratio (in oven)    | 3 – 7 Differential velocity ratio |                        |
| Yarn relaxation ratio (on hot rolls)| 0.7 – 1 Differential velocity ratio |                        |
| Number of ovens                    | 1 – 2 Typically 1        |                        |
| Oven temperatures                  | 60 – 140 ºC              |                        |
| Godet with individual drives       | 3 – 10 m and godet diameter |                        |
| Temperature of godets              | 20 – 130 ºC              |                        |
| Die waterbath distance             | 10 – 100 mm              |                        |
| Extrusion melt temperature         | 190 – 250 ºC             |                        |
| Oven length                        | 3 – 7 m                  |                        |
| Yarn linear weight                 | 1000 – 20000 dtex        |                        |
| Yarn shape                         | Flat fibrillated tape    |                        |
| Additives                          | UV, Color,…              |                        |
| Oven type                          | hot air                  |                        |

Optimal operating parameters to produce fibrillated tape of high quality depend on the given extrusion line and on the specific resin used. Considering resin 1, a stretching ratio of 5, an oven temperature of 95ºC and a line speed after the oven of 110m/min will allow for good fibrillation of the stretched tape. However, changing from resin 1 to a resin with density below 0.920 g/cc (e.g. resin 3) while maintaining all processing conditions identical will result
in a stretched tape which is very difficult if not impossible to fibrillate. Adapting and optimizing process conditions for each resin is therefore critical to obtain high quality fibrillated turf yarn. The different experiments and measurements of tear resistance in machine direction (following ASTM standard D-1922) as well as sample thickness are shown in Table 3. The value of tear resistance has been normalized by sample thickness to allow for easier comparison.

Table 3. Elmendörfer tear resistance in machine direction (ASTM D-1922) and sample thickness of either unstretched or stretched tapes made of different LLDPE resins.

|                | Density [g/cc] | Unstretched |                          |                          |
|----------------|---------------|-------------|--------------------------|--------------------------|
|                |               | Tear MD g/| Thickness micron         | Tear MD g/|Thickness micron |
|                |               | micron      |                          | micron                   |
| Resin 1        | 0.935         | 1.85        | 20                       | 0.28                     | 88                       |
|                | 0.935         | 2.86        | 22                       | 0.25                     | 110                      |
|                | 0.935         | 5.08        | 208                      | 0.095                    | 111                      |
|                | 0.935         | 0.28        | 88                       |                          |                          |
|                | 0.935         | 0.25        | 110                      |                          |                          |
|                | 0.935         | 0.36        | 153                      |                          |                          |
| Resin 2        | 0.917         | 9.36        | 23.4                     | 0.917                    | 17.1                     |
|                | 0.917         | 17.1        | 100                      |                           |                          |
|                | 0.917         | 0.13        | 161                      | 0.906                    | 104                      |
| Resin 3        | 0.918         | 14.3        | 100                      | 0.918                    | 14.8                     |
| Resin 7        | 0.918         | 3.35        | 100                      | 0.918                    | 3.35                     |
| Resin 8        | 0.918         | 3.86        | 100                      | 0.918                    | 3.86                     |
| R1 + 35% R2    | 0.929         | 0.53        | 88                       | 0.921                    | 0.53                     |
| R1 + 65% R2    | 0.924         | 0.7         | 91                       | 0.924                    | 0.7                      |
| R1 + 23% R4    | 0.928         | 0.72        | 90                       | 0.928                    | 0.72                     |
| R1 + 25% R10   | 0.928         | 1.07        | 89                       | 0.928                    | 1.07                     |
| R1 + 10% R11   | 0.928         | 1.03        | 93                       | 0.928                    | 1.03                     |
| R1 + 20% R10   | 0.93          | 0.4         | 110                      | 0.93                     | 0.4                      |
| R1 + 40% R10   | 0.925         | 0.55        | 105                      | 0.925                    | 0.55                     |
| Resin 6        | 0.918         | 10.88       | 23.8                     | 0.918                    | 10.88                    |
| Resin 5        | 0.916         | 14.08       | 21.3                     | 0.916                    | 14.08                    |
| Resin 5        | 0.916         | 17.8        | 100                      | 0.916                    | 17.8                     |

The data measured for resin 1 demonstrate that tear resistance decreases with increase of molecular orientation. The stretched tape versus the unstretched one has approximately a 10 times lower tear resistance which further decreases at higher stretch ratio. Comparing resin 1 with resin 2, which has a much lower density, shows the significantly higher tear resistance of the lower density resin 2, for both unstretched and stretched tape. The data on unstretched tape for resin 2, 3, 7, 8, and 9 confirm the highest tear resistance for resins with octene comonomer for densities around 0.918 g/cc. The lower density compared to resin 1 also provides improved softness of the yarn, which is often desired for player comfort [2, 8]. The series of experiments evaluating stretched tapes of blends of resin 1 with resins 2, 4, 10 and 11 show the increasing tear resistance with decreasing density and the influence of the resin type and blend concentration. The best performing resin among those investigated in terms of tear resistance of unstretched and stretched tape is resin 5, a metallocene based LLDPE.

As indicated above, the higher tear resistance of lower density resins can cause difficulties during fibrillation of the resin. The attempt to fibrillate the blends of resin 1 with resins 2, 4, 10 and 11 resulted in tape breaks. The tape could not be cut efficiently at the specified stretching ratio of 5 and wrapped around the fibrillator. An identical outcome was observed when trying to fibrillate resin 8 at a stretch ratio of 5. In order to fibrillate the lower density resins as well, one has at least two straightforward approaches available. At a chosen stretching ratio one can...
decrease the overall resin density via blends with other resins until fibrillation becomes difficult and the lowest resin density for successful fibrillation has been identified. The other option is to choose a low density resin and start at a high stretching ratio of 8, e.g. At this stretch ratio the tear resistance even of a resin with high tear resistance will have been decreased to allow fibrillation. Subsequently the stretching ratio is decreased until fibrillation is no longer achievable. Both of these approaches have been used to construct Figure 1, which shows which combinations of stretching ratio and density allowed to produce fibrillated tape and for which combinations fibrillating the tape was not possible. For these experiments similar overall processing conditions (like oven temperatures, extruder output, line speed) and extrusion line setup were used. It may be possible to fibrillate the resins at stretch ratio and density combinations marked by red squares by substantially changing line configurations and setup, although this has not been attempted in this work.

Figure 1. Possibility of fibrillation for combinations of resin density and stretching ratio indicated by: red open squares – fibrillation not possible; green full triangles – fibrillation possible.

After completing the objective of fibrillating tapes made of resins with a high tear resistance, the mechanical properties of these fibrillated tapes need to be optimized for artificial turf applications. Table 4 compares process settings and selected mechanical properties for two fibrillated tapes made with resin 5. The tapes were processed on a standard fibrillated tape line with one hot air oven used for stretching followed by six hot rolls in front of the fibrillator with another six hot plus two cold rolls after the fibrillator to anneal the tape and reduce the residual shrinkage.

Table 4. Processing parameters and fibrillated tape properties made with resin 5. Linear weight (dtex = weight of yarn per 10000m length) was measured by taking the weight of 50m tape and extrapolation to 10km. Tenacity and residual elongation were measured on a Zwick tensile tester on a filament length of 260mm and an extension rate velocity = 250mm/min until filament break. Tenacity is defined as the tensile force (cN) at break divided by the linear weight (dtex). Residual elongation is the strain at fiber break. Shrinkage is measured as the % length reduction of 1 meter of filament after inserting in 90°C hot silicon oil for 20 seconds.

|                  | Stretch | Stretch |
|------------------|---------|---------|
| Melt temperature | 230     | 230     |
| Line speed m/min | 96.8    | 91      |
| Oven T           | 95.1    | 95      |
| Relaxation rolls 1| 95.3    | 99.7    |
| Relaxation rolls 2| 100     | 103.2   |
| dtex             | 8850    | 10000   |
| cN/dtex          | 2.14    | 1.39    |
| elongation %     | 22.9    | 35.2    |
| Shrink %         | 25      | 18      |
The reduction of the stretching ratio from 7 to 6 in combination with a higher temperature of the relaxation roll improved the shrinkage from 25 to 18%. This value is still too high for artificial turf yarn. Minimizing shrinkage is important to reduce residual stress present in the stretched tapes after orientation. These residual stresses can cause thermally induced shrinkage during turf carpet tufting or after pitch installation, when exposed to high outside temperatures and multidimensional stresses in use. Therefore additional measures need to be taken to reduce the shrinkage in order to process resin 5 into high quality turf yarn. On a given extrusion line, as used for the experiments described above with a fixed number of hot relaxation rolls, the best option to decrease shrinkage is by increasing the resin density, e.g. by blending quantities of resin 1 with resin 5, for example.

With the objective to use resin 5 without blending another higher density resin, measures need to be taken on the machinery side to reduce shrinkage. In monofilament extrusion [2, 8], hot air ovens are typically used to reduce residual shrinkage of the filament instead of hot rolls. For shrinkage reduction especially for lower density LLDPE like resin 2, the installation of an additional oven for thermally annealing the tape further proved useful. Consequently, options include the installation of additional hot rolls or using hot ovens instead of a series of hot rolls for the annealing process. The aim of such line modifications is increasing the overall thermal energy transferred to the tape in order to maximize the relaxation of the oriented molecules.

The motivation to use low density LLDPE resins such as resins 2 and 5 for fibrillated tape originates from material science arguments we have presented in refs [2, 8]. It has been shown that the abrasion resistance of resins 2 and 5 is superior to resins with higher density or LLDPE materials of similar density but polymerized with butene comonomer. LLDPE is substantially a linear polyethylene molecule with short side chains created through the selective incorporation of butene, hexene or octene monomers. Octene will provide a longer side chain than butene and will create a different semicrystalline network – which provides a better tear resistance and generally superior mechanical properties [9, 10]. This has been confirmed in cyclic stress loading experiments where longer comonomer chains like octene (butene, hexene and octene were investigated) result in a significantly larger number of cycles before cracks develop in the material leading to failure [11].

In conclusion, we have shown the influence of machine direction tear resistance on the fibrillation process of oriented tapes. We have demonstrated how a high tear resistant LLDPE tape can be fibrillated and indicated how the rather high residual shrinkage observed on the given standard machinery can be reduced by process setup modifications. We provided material science arguments and data which substantiate why low density LLDPE resins made with octene comonomer provide high quality artificial turf yarn.

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