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Bending force of LLDPE monofilaments at high temperatures measured in DMA (Dynamic Mechanical Analyzer)

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Abstract

The bending force of monofilaments used as pile layer in artificial turf football fields is a very important property due to the strong relation with the performance of the entire system being the force that mostly influences the deformation of monofilaments. The existing test methods for measuring this force can only be used to perform tests at room temperature. Nowadays, artificial turf surfaces are being installed worldwide, even in regions with very high values of air temperature, leading to the need of evaluating the performance of monofilaments and thus, of testing their bending force at elevated temperatures.

The aim of this paper is to use the DMA's advantage of testing at high temperatures, by using a new test method developed for measuring the bending force of monofilaments at room temperature and to evaluate the results obtained. For this purpose, six different LLDPE (Low Linear Density Polyethylene) monofilaments are tested at temperatures 25°C, 50°C and 80°C and the bending force is measured. The DMA is used successfully on performing tests at high temperatures. Considering the results, an analysis of the bending behavior of LLDPE monofilaments depending on the temperature is done. All fibers show the same trends regarding this influence, with decreasing of the bending force while increasing the temperature.

1. Introduction

The use of artificial turf fields in sports and other surfaces has been increased recently [1]. There have been great and continuous improvements over the years on these fields [2, 3]. So, although their first installations were made in regions with low air temperatures, nowadays synthetic turf surfaces are being installed more and more, even in locations where the air temperature is qualified high.

Artificial turf systems are mostly used in football fields and with football being the most popular sport in the world, the geography of installing and using these fields is worldwide. High temperatures are one of today's problems of the world of football. They have an impact not only on footballers in form of health problems and their playing performance, but also in the artificial turf field, by affecting the performance of the fibers and the whole system [4]. Values up to 50°C, are reached in many regions where artificial grass field systems are already, or aim to be installed. The air temperature in these locations can sometimes reach up to 70°C in the sun. With artificial turf fields being mainly produced from linear low density polyethylene (LLDPE) monofilament, and with this polymer being sensitive to high temperatures [5-7], it is strongly needed to test and evaluate their behavior in high temperatures. The force that mostly influences the deformation of the fibres is the bending force [8].

A new method consisting on testing the bending force of monofilaments on the DMA, was developed successfully [9]. The DMA has a great advantage compared to other test methods used to measure the bending force of the fibers, because the tests can be performed at elevated temperatures [10].

The bending force of all samples is measured on the DMA at two high temperatures, besides the room temperature. Based on the results obtained from the tests, an analysis of the bending behavior of LLDPE monofilaments depending on the temperature and the distance of the applied force is done.

2. Materials

For this study were used six different Linear Low Density Polyethylene (LLDPE) monofilaments fibers (denoted A-F) The linear density is measured for the six fibers and the cross section of each fiber is observed in the microscope. The measurements of both linear density and cross section were performed at the University of Gent laboratories, Department of Textile. The values of the linear density (Tex) for each fiber are respectively: A=205, B=225, C=149, D=208, E=225, F=206. The cross sections of the fibers were of different shapes. There are two diamond shape fibers, A and E, but slightly different in the extension of the sides, and they also differ in the linear density. Two other fibers, B and F, are almost "c" section. The "c" shape has two sides: the concave side denoted as (l) and the convex side denoted as (m). The last two fibers are of different shapes, where fiber C is almost rectangular shaped, while fiber D has a small ball in the center.

3. Test method

DMA TA Instrument was used to perform the measurements of the bending force. The testing is performed at the Department of Textile at University of Gent. The Single Cantilever is used for clamping the fiber in one side and the DMA is set to Controlled Force Mode [10]. The distance of applying the force is set to 2 mm and 3 mm. The temperature is set at the required value (25ºC, 50ºC and 80ºC). The DMA device is equipped with a closed oven, which not only achieves temperature set, but also keeps this temperature unchanged during the testing. Fibers B and F are tested in both sides of the "c" shape, because they perform differently in each of the sides [11]. The TA Instruments Universal Analysis (UA) Program is used for data analyses [12]. The static bending force (N) is plotted versus the displacement (μm) and The Onset Point (OP) 1 and Onset Point (OP) 2 are found in each graphic, through the UA Program (Figure 1). The Onset Point determines the force at which a change in the curve occurs [13], where the Onset Point 1 represents the bending force where the deformation starts but it can still be reversed. From the Onset Point 1 to the Onset Point 2 the deformation continues and on the Onset Point 2 can be considered as the breaking point. The same plot as below is obtained for each repetition of each sample.
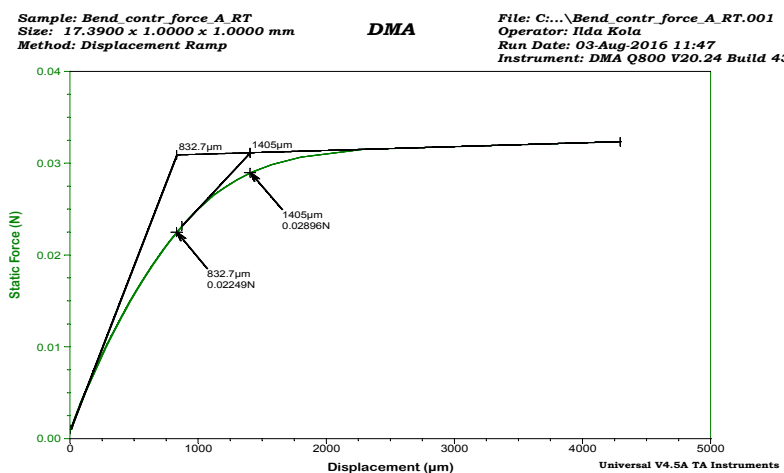

**Figure 1.** Bending force of fiber A versus displacement and the Onset Points on the DMA.

4. Results and discussions

The testing of all fibers was performed at 25ºC, corresponding to the room temperature, and two high temperatures corresponding to 50ºC and 80ºC on two distances of the applied force (2 and 3mm).

Fibers A and B (both sides) were tested at three temperatures at both distances, while other fibers (C, D, E, F) were tested at three temperatures only on the distance of 2 mm, while on 3mm, the testing was carried out at 25ºC and 50ºC, because the changing values trend was the same as on the 2 mm distance and similar to fibers A and B. For each fiber 3 repetitions are performed.

For each measurement the bending force is plotted versus the displacement as showed above. After each plot was obtained, the bending force values on the Onset Point 1 and 2 are located (see Figure 1) and the mean value was calculated for each fiber, at three temperatures and both distances.

In order to evaluate the changing of the bending force at elevated temperatures, the plots of each fiber per each temperature are overlaid separately for each distance. This was accomplished for fiber A and B, for which the overlaid plots at three temperatures on both distances of the application force are obtained (Figure 2, 3).
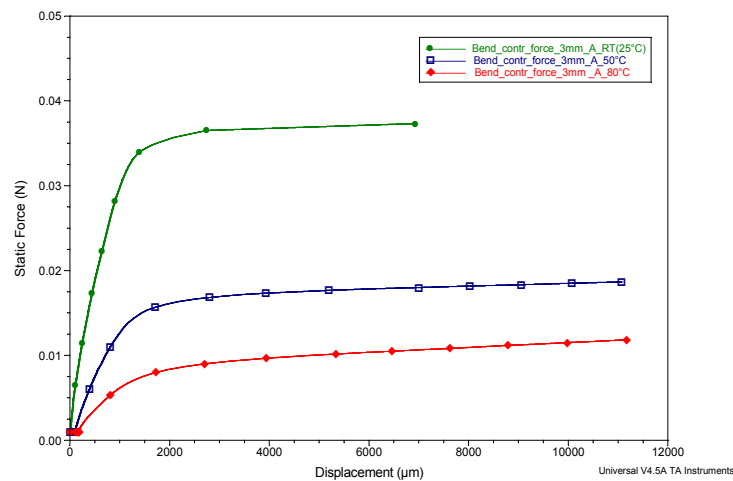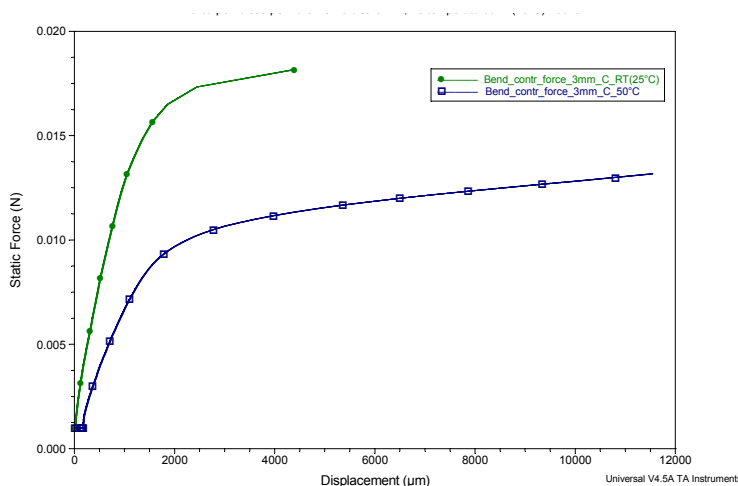

Figure 2. Bending force for fiber A, on 3 mm distance, at RT, 50ºC and 80ºC.
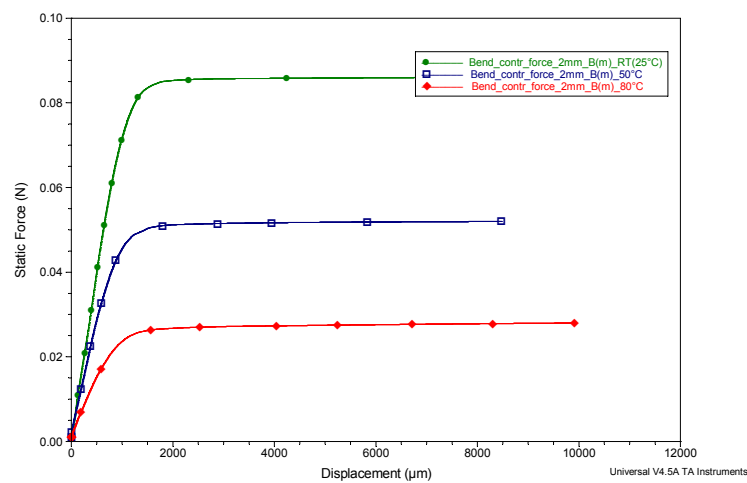
Figure 3. Bending force for fiber B(m), on 2 mm distance, at RT, 50ºC and 80ºC.

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For the remaining fibers (C÷D) the overlaid plots of two temperatures on the 3mm distance were obtained (Figure 4).

Regarding the overlaid plots, it is obvious that the performance of each fiber is different at each temperature. So, with the increasing of temperature, the bending force was reduced significantly and at 80ºC, the fibers exhibited a really poor bending performance (Figure 2, 3, 4). This applies to all fibers on both distances.

Figure 4. Bending force for fiber C, on 3 mm distance, at RT and 50ºC .

Since it is impossible to show all the overlaid plots on the paper, the results of the bending force values on the Onset Points 1 and 2 for each fiber, for both distances and different temperatures were represented on Table 1. Based on the force values obtained, a better and more accurate analysis on how the bending force depends on the temperature was done.

Table 1. Bending force values at Onset Points 1 and 2, for both distances and three temperatures.

Fiber sample	Onset Points	Bending force (cN)					
		RT (25°C)		50°C		80°C	
		2 mm	*3mm*	2 mm	*3mm*	2 mm	*3mm*
Fiber A	OP 1	3.361	*2.272*	1.944	*1.119*	1.178	*0.61*
	OP 2	4.243	*3.213*	2.586	*1.466*	1.43	*0.83*
Fiber B(l)	OP 1	4.669	*2.759*	3.055	*1.636*	1.571	*1.057*
	OP 2	6.115	*3.543*	4.058	*2.184*	2.024	*1.332*
Fiber B(m)	OP 1	7.433	*3.465*	3.919	*2.268*	2.083	*1.448*
	OP 2	8.278	*4.291*	5.090	*2.980*	2.568	*1.866*
Fiber C	OP 1	2.21	*1.101*	1.188	*0.768*	0.559	*NA*

	OP 2	2.8076	*1.401*	1.453	*1.044*	0.785	*NA*
Fiber D	OP 1	3.125	*1.423*	1.162	*0.636*	0.599	*NA*
	OP 2	3.869	*1.764*	1.5086	*0.858*	0.827	*NA*
Fiber E	OP 1	4.717	*2.299*	2.159	*1.064*	1.124	*NA*
	OP 2	6.121	*2.809*	2.8496	*1.588*	1.438	*NA*
Fiber F(l)	OP 1	2.835	*1.672*	1.39	*0.863*	0.836	*NA*
	OP 2	4.474	*2.2556*	1.984	*1.228*	1.153	*NA*
Fiber F(m)	OP 1	6.124	*3.625*	3.028	*3.028*	1.649	*NA*
	OP 2	6.69	*4.168*	3.517	*3.518*	1.904	*NA*

The results show that the reduction of bending force values was quite high when passing from room temperature to 50ºC. As it can be noticed from the plots and the table, for all fibers, and for both distances, there is a decrease by almost 50% on the values obtained at 50ºC temperature compare to those obtained at 25ºC. This can be explained with the changes that occur in the molecular structure of the polymer. So, the LLDPE polymer is stable and no changes occur on its internal structure, when exposed to temperatures up to 40ºC [6, 7]. At temperatures higher than 50ºC, internal molecular movements start, causing changes in the inside structure of the polymer, and consequently also in its mechanical properties [7]. This is reflected on the significant changes of the bending force values at 50ºC temperature.

Regarding the bending force values at 80ºC (Table1), to be noticed is another decrease of almost 50%, compared to those obtained at 50ºC and a high reduction on these values while compared to the values obtained at 25ºC. This is due to the increasing of the internal molecular movements causing changes on the polymer chains and increasing the disorder on the internal structure of the material [6]. The LLDPE fibers are estimated working up to temperatures 65-70ºC resulting on a very high loss of their properties when exposed to higher temperatures [7]. This is the reason why they show a significant drop in performance, reflected in big changes of the bending force values at 80ºC.

When comparing the performance of the fibers at high temperatures, is noticed that the better performing fiber is B on the convex side followed by fiber F on the same side and fiber E, while the worst performing fibers are C and D. For both distances, the same conclusion applies. This is explained with the cross section shape of the fibers [11].
Also, the highest values of the bending force are encountered while testing the fibers at high temperatures on the 2mm distance of the applied force, in analogy with the room temperatures measurements [13].

So, when tested at high temperatures, the fibers show the same tends of performance as they show when tested at 25ºC [11, 13]. This results to a successful testing on the DMA at elevated temperatures.

5. Conclusions
The testing of the LLDPE monofilaments on the DMA at elevated temperatures, other than room temperature and the evaluation of the bending force measured depending on the temperature was the purpose of this paper. Six different monofilaments of LLDPE were tested at 25ºC, 50ºC and 80ºC and in 2 and 3 mm distance of applying the force.

The challenge of using DMA for testing at elevated temperatures was successfully accomplished.

From the analysis of the bending force values obtained, resulted that fibers exhibited significantly lower performance at higher values of temperature than 25ºC. Thus, the bending force at 50ºC temperature was reduced by almost 50% compare to 25ºC temperature, and at 80ºC the force values were also reduced by almost 50% compare to those at 50ºC. The same principle applies to all fibers on both distances. This is due to the influence of the temperature on the inside molecular fiber movements and changes occurring in the polymer chains, which increases the disorder in the internal structure, resulting in loss of fiber properties.

Considering the performance of each fiber for the same high temperature, the results show that the better performing fibers were the "c" shaped fibers, B and F on the convex side and the worst performing were fibers D and C. This is in full analogy with the fibers performance at 25ºC.

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