

Comparison between New Developed Test Method (Using DMA) and the Existing One for Measurement of the Bending Force of Monofilaments

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ABSTRACT: The measurement of the bending force of monofilaments used in synthetic sport fields, which determines the quality and the performance in long terms, is still a main discussion on the world of artificial turf. This leads to the need of having precise results of the bending force measured and having the possibility of doing it on different conditions. A new test method has been developed by modifying the DMA equipment in order to use it for measuring the bending force. The results from the measurements are compared with the results from the existing method, Favimat.

The aim of this paper is to find a correlation between these two test methods. The monofilaments used are Low Linear Density Polyethylene (LLDPE) and two different distances of applied force are used on the DMA measurement. The comparison of the results showed a good correlation between the two methods on the bending force measured on the 3 mm distance on the DMA and the second cycle on the Favimat.

KEYWORDS: Bending force, LLDPE monofilaments, Coefficient of correlation, Favimat R, DMA.

I. INTRODUCTION

The performance of artificial turf, although widely accepted in different sports, is still one of the main discussions in terms of long life service and quality. Artificial turf is composed by different layers [1, 2] and following the way of producing, it seems that the pile layer is the key for long term performance [3]. In addition, pile layer is composed by LLDPE fibres which are fixed on the backing part of the product -carpet [1]. The fibres are fixed through the coating process. In this stage, the carpet undergoes a heating process which brings the fibres to a temperature at 80°C [4]. Among several properties, determining the performance of the final product, the ability of the pile layer to stand different deformation forces is the most discussed property [5, 6]. These because the pile layer has a direct impact on ball roll distance and ball rebound [8], and also it influences on the performance of the players [3]. The force that mostly influences the deformation of the fibres is the bending force [4]. One of the test methods mostly used for measuring the bending force is the FAVIMAT R [8]. Among several advantages of this test method, there are still some limitations like testing in different temperatures and taking time. Testing in temperatures higher than room temperature is very important as the artificial turf, in real life, undergoes higher temperatures.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

A new method is developed by modification made on the University of Ghent in the DMA equipment in order to take advantages that DMA offers. Some of these advantages are testing at elevated temperatures, saving time and taking very précised results.

This paper will be focused on comparing the received results of bending forces from both test methods and finding what correlation they have, as one of the forms to validate a new test method. The comparative approach states that the test method is assessed by comparing its results to those obtained by means of another already validated test method, which has been developed for the same purposes [9].

II. MATERIALS

Six different Linear Low Density Polyethylene (LLDPE) monofilaments fibers were used. Fibers are heat treated at 80°C, for one hour. This treatment is done in order for the fibers to be in the same conditions they are after the carpet is produced [4]. 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, according to the standard conditions. The linear density varies from 205 to 225 Tex.

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 and the convex side. 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.

III. TEST METHODS

The existing test method – Favimat R. The first test method used is the FAVIMAT R (Textechno). This is a dynamic bending test performed regarding the Standard PM 1301 [8]. The normal set up of the instrument (for tensile testing on one single filament) was modified (see Fig. 1a) to be able to test the bending force of one monofilament.

The method consists on bending the free side of a single filament. The filament is clamped in one side, while the other side, denoted as the free side, undergoes a perpendicular bending force for 300 times. The distance from the clamping point and the bending point is 2.87mm. This is the point where the force is applied. The filament has a free length of 17.5 mm (see Fig. 1b), which is corresponding to the average free pile length in the artificial turf system.

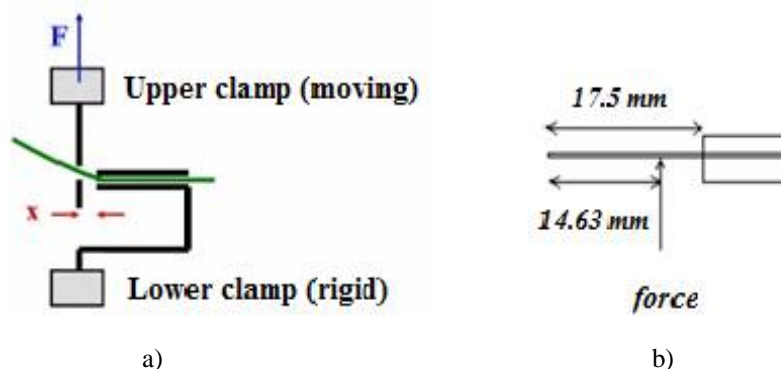


Fig 1.a) Schematic presentation of the bending test on Favimat R and b) test setup [7]

The test speed is 100mm/min and the preload force applied is 0.01cN. The deflection varies from a minimum of 2mm to a maximum of 8mm. The force needed to cause the deflection is monitored in both advancing and receding part of each cycle. The total duration for one test is 40 minutes. For each fiber are performed 4 tests.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

The testing conditions are 23°C and 65 % R.H. For each cycle is measured the maximum force and the results for the 300 cycles are displayed in a table (see Table 1) and a graphic (see Fig. 2) from the FAVIMAT program. The same table and graph is obtained for each fiber separately. Fibers B and F are tested in both sides of the “c” shape, the concave side denoted as (l) and the convex side denoted as (m), because the fiber performs differently in each of the sides.

Table 1. Maximum bending force (for fiber A) for each cycle (1÷300) in Favimat testing.

Test:	1	2	3	4	Mean	1	2	3	4	Mean
Cycle	F (cN)	F (cN)	F (cN)	F (cN)	F(cN)	F (%)	F (%)	F (%)	F (%)	F (%)
1	2.527	2.276	4.043	3.576	3.106	100.0	100.0	100.0	100.0	100.0
2	1.716	1.536	2.311	2.263	1.957	67.9	67.5	57.2	63.3	63.0
3	1.573	1.431	2.125	2.062	1.798	62.2	62.8	52.6	57.7	57.9
4	1.506	1.366	2.037	1.967	1.719	59.6	60.0	50.4	55.0	55.3
5	1.46	1.323	1.978	1.888	1.662	57.8	58.1	48.9	52.8	53.5
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
100	1.176	1.061	1.544	1.472	1.313	46.5	46.6	38.2	41.2	42.3
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
299	1.144	0.98	1.44	1.357	1.230	45.3	43.1	35.6	38.0	39.6
300	1.143	0.981	1.443	1.357	1.231	45.2	43.1	35.7	37.9	39.6

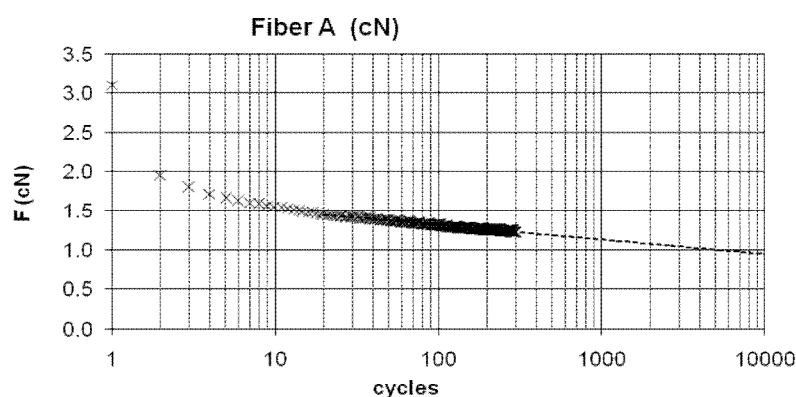


Fig. 2. The measured bending force (for fiber A) in function of the number of cycles in the Favimat R.

The new test method - DMA (Dynamic Mechanical Analyzer). The new test method is by using the DMA (Dynamic Mechanical Analyzer) TA Instrument. The testing is performed by modifying the DMA instrument, in order to use it for bending. The modification is done by 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].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

The distance of applying the force is set to 2 mm and 2.9 mm. The detailed information is restricted from the University of Gent. In this test, the bending force is measured for a single monofilament.

For each fiber are performed 3 repetitions. The testing is done at the room temperature, which corresponds to $23 \pm 20^\circ\text{C}$. Fibers B and F are tested in both sides, for the same reason explained in the paragraph 2.1. FAVIMAT R. For data analyses is used the TA Instruments Universal Analysis (UA) Program [11]. For the 3 measurements of each fiber, the static bending force (N) is plotted versus the displacement (μm). The Onset Point (OP) 1 and Onset Point (OP) 2 are found in each graphic, through the UA Program and the mean value is calculated. Onset Point is defined as the intersection of an initial tangent line with a final tangent line (see Fig. 3). The Onset Point determines the force at which a change in the curve occurs [12]. The same plot as below is obtained for each repetition of each sample.

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 it can be considered as the breaking point.

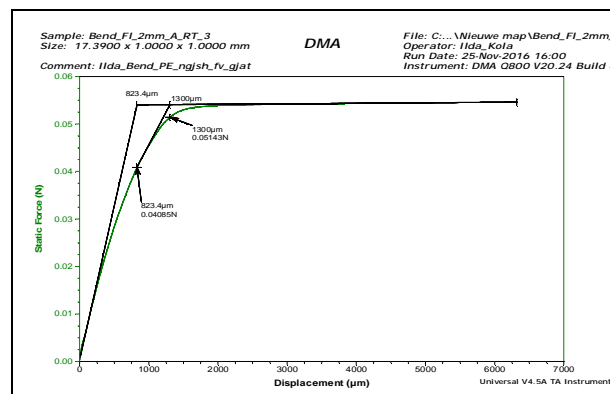


Fig. 3. The bending force of fiber A versus displacement and the Onset Points on the DMA

IV. RESULTS AND DISCUSSIONS

The measured bending forces of each fiber resulting from both test methods, the FAVIMAT R and the DMA are summarized in Table 2. For the FAVIMAT testing, the bending force for cycles 1 and 2 are taken into consideration, while for the DMA testing, and are considered the bending forces corresponding to the Onset Points 1 and 2, as shown in the test method paragraph (see Table 2).

In order to compare a new method with the existing one, the results from both methods should be listed in pairs (see table 2) where each pair represents the same sample.

The results from the methods are presented graphically, where X- axis represents the reference existing method and the Y-axis represents the results from the new method. By combining the values of the bending forces, measured in both methods, were created eight scatter plots (see figures 4-12). The combinations were made between two distances and two Onset Points of the new method (DMA) and the first two cycles of the existing method (FAVIMAT R).

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

Table 2. The bending forces measured in both methods used.

Fiber Sample	Testing method used					
	FAVIMAT - testing		DMA - testing			
	Bending force for each cycle (X)		Bending force for the distance where it is applied (Y)			
	Cycle 1	Cycle 2	2mm		3mm	
	F1 (cN)	F2 (cN)	OP 1 (cN)	OP 2 (cN)	OP 1 (cN)	OP 2 (cN)
Fiber A	3.106	1.957	3.361	4.243	2.272	3.213
Fiber B(l)	3.982	2.867	4.669	6.115	2.759	3.543
Fiber B(m)	4.798	3.2175	7.433	8.278	3.465	4.291
Fiber C	1.517	1.099	2.21	2.807	1.106	1.401
Fiber D	1.702	1.226	3.125	3.869	1.423	1.764
Fiber E	3.343	2.026	4.717	6.121	2.299	2.809
Fiber F(l)	3.278	1.717	2.835	4.474	1.672	2.256
Fiber F(m)	4.982	3.116	6.124	6.69	3.625	4.168

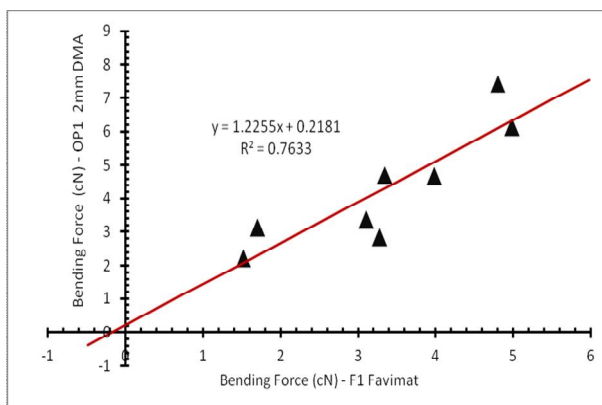


Fig.4. The plot representing the correlation between the bending force of the first cycle of Favimat and the OP1 measured on the 2mm distance on the DMA, for all fibers.

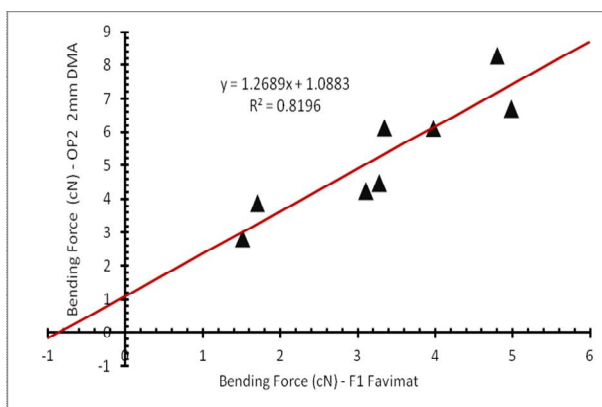


Fig.5. The plot representing the correlation between the bending force of the first cycle of Favimat and the OP2, measured on the 2mm distance on the DMA, for all fibers.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

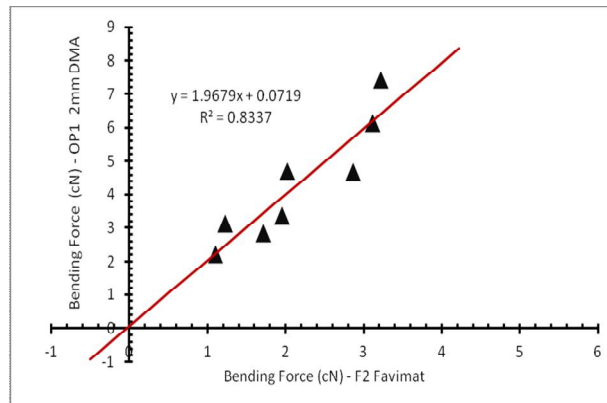


Fig.6. The plot representing the correlation between the bending force of the second cycle of Favimat and the OP1, measured on the 2mm distance on the DMA, for all fibers.

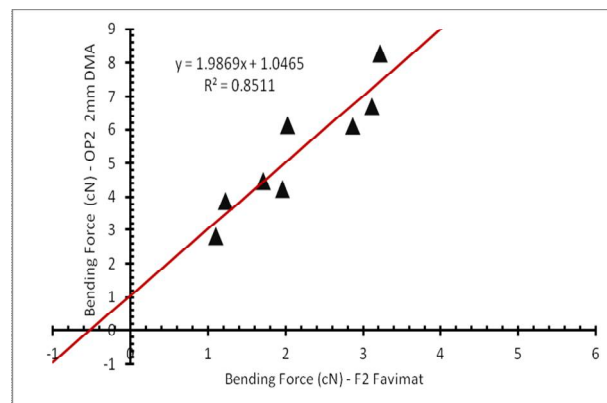


Fig.7. The plot representing the correlation between the bending force of the second cycle of Favimat and the OP2, measured on the 2mm distance on the DMA, for all fibers.

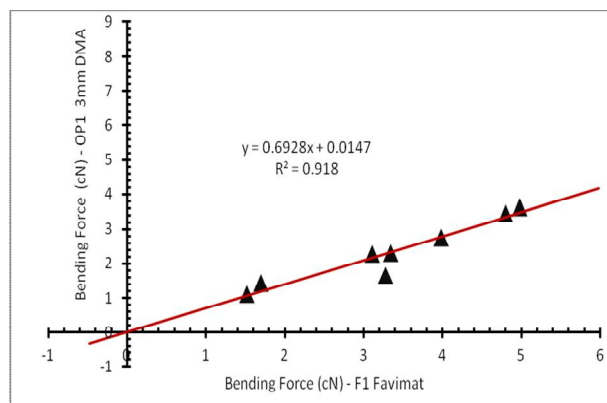


Fig.8. The plot representing the correlation between the bending force of the first cycle of Favimat and the OP1, measured on the 3mm distance on the DMA, for all fibers.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

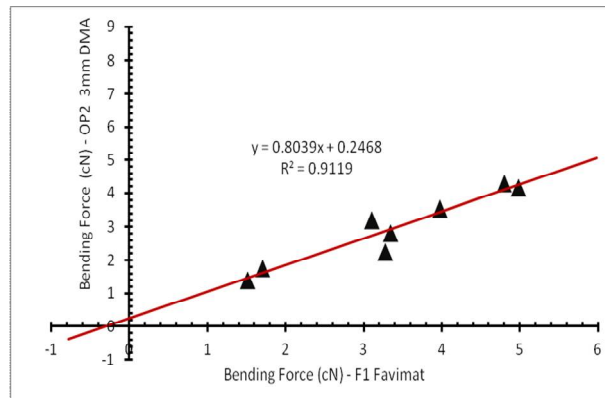


Fig.9. The plot representing the correlation between the bending force of the first cycle of Favimat and the OP2, measured on the 3mm distance on the DMA, for all fibers.

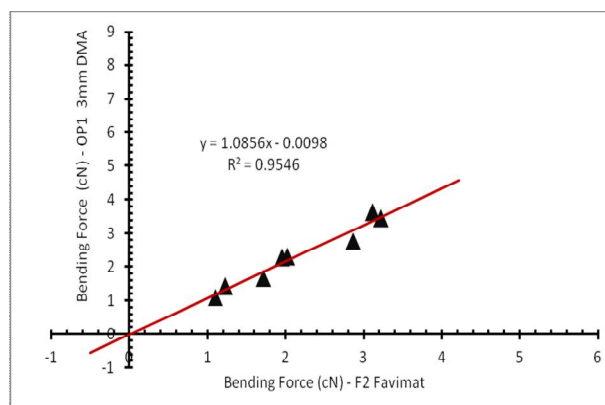


Fig.10. The plot representing the correlation between the bending force of the second cycle of Favimat and the OP1, measured on the 3mm distance on the DMA, for all fibers.

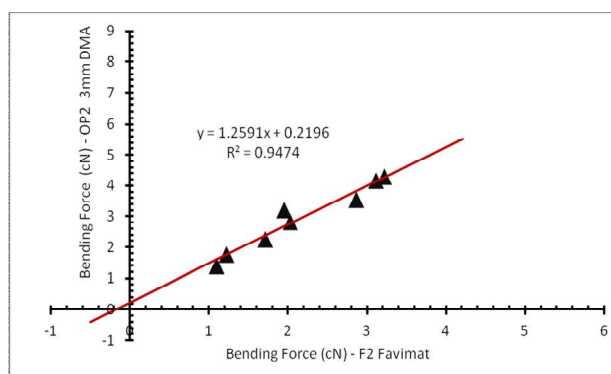


Fig.11. The plot representing the correlation between the bending force of the second cycle of Favimat and the OP2, measured on the 3mm distance on the DMA, for all fibers.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

On the plot, the relation between methods is given by the linear regression equation and the correlation coefficient ($r = \sqrt{R^2}$). The correlation coefficient “r” is a statistical term and is used to assess the correlation between the reference method and the new method. Ideally, “r” should be 1 and it can range from +1 to -1. An r of -1 indicates a perfect negative linear relationship between variables, an r of 0 indicates no linear relationship between variables, and an r of 1 indicates a perfect positive linear relationship between variables [13, 14]

The coefficient of the correlation is influenced by random errors only and accuracy of the method should not be based on it.

The linear regression evaluates the relationship between two variables by fitting a linear equation to observed data. A linear regression line has an equation of the form $y = mx + b$, where x is the independent variable and y is the dependent variable [15]. In this equation “m” is affected by slope and indicates the proportional error while “b” represents the intercept (the value of y when $x=0$) and indicates the constant error; both represent the systematic error. To evaluate the linear regression line the slope and the intercept should be considered. The slope “m” should be between 0.9 and 1.1; the intercept “b” should be close to zero [15].

All the results from the plots above, including the equation of the linear regression line, the correlation coefficient “r”, the slope “m” and the intercept “b”, are represented in table 3, in order to have a better comparison of the scattered plots and to find the best correlation between the two methods.

Table 3. The elements of linear regression line to be considered on comparing the methods.

Plot no	Linear regression line equation $y = mx + b$	Slope m	Intercept b	Correlation coefficient $r = \sqrt{R^2}$
Plot 4	$y = 1.2255x + 0.2181$	1.2255	0.2181	0.8736
Plot 5	$y = 1.2689x + 1.0883$	1.2689	1.0883	0.9053
Plot 6	$y = 1.9679x + 0.0719$	1.9679	0.0719	0.9131
Plot 7	$y = 1.9869x + 1.0465$	1.9869	1.0465	0.9225
Plot 8	$y = 0.6928x + 0.0147$	0.6928	0.0147	0.9581
Plot 9	$y = 0.8039x + 0.2468$	0.8039	0.2468	0.9549
Plot 10	$y = 1.0856x - 0.0098$	1.0856	- 0.0098	0.9770
Plot 11	$y = 1.2591x + 1.0883$	1.2591	1.0883	0.9733

From the data gathered in table 3, is observed that plots from 4 to 7 (see table 3), don’t show a good correlation between two methods, this according to the values of correlation coefficient and the linear regression line equation, mining the values of slope and intercept. The values for these plots are not close to the values mentioned on the theoretical explanation above, regarding the values of “r”, “m” and “b”. All these plots represent the relation between the bending force measured on the reference method Favimat (X) and the bending force measured on the 2mm distance of applied force on the new method DMA (Y). These not strong relations might come because of the difference on the distance where the force is applied, which changes from 2.87mm in Favimat to 2mm on DMA.

The last four plots, 8 to 11 (see table 3), represent the relation between the same forces measured on Favimat and the forces measured on DMA, but in 3mm distance of applied force, which is very close to the Favimat distance. From the data on the table 3 are observed higher values of the correlation coefficients on the four last plots, but the values of slope and intercept differ significantly.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

The last two plots, 10 and 11, have the highest values of “r” between all the plots, but the difference on the values of “m” and “b” is very noticeable. They represent the relation between the bending force measured on the second cycle of the Favimat and the bending force measured on 3mm distance on the DMA, specifically OP1 and OP2.

In conclusion, the strongest correlation coefficient is $r = 0.9770$, because is closer to 1.[13,14], compare to the other values.

The best value of slope is $m = 1.0856$, which is between 0.900 and 1.100 as explained theoretically [15]. All the other values are higher or lower than that range.

Also, the best value of intercept is $b = -0.0098$, which is closer to zero. [16]]

According to these results, it is obvious that all best values, including “r”, “m” and “b”, belong to Plot 10. This plot represents the bending force of the second cycle measured on Favimat and the bending force (OP1) measured in 3 mm distance of applied force on the DMA. Therefore, this is the strongest correlation between the two methods. This result can be explained in terms of the distance of applied force which is almost the same, and in terms of the bending force measured. The Onset Point 1, measured on DMA, represents the bending force where the deformation starts but it can still be reversed (see paragraph 2.2). This force is similar to bending force measured on the second cycle of Favimat, which in difference from the first cycle, completes a full reversed cycle.

V. CONCLUSION

The aim of this paper was to compare a new test method for measuring bending force of monofilaments, developed at University of Ghent, Department of Materials, Textile and Chemical Engineering, with an exciting test method, also developed at the same department.

The reason for developing this new test method was to extend the range of testing temperatures and profiting from the advantages of the equipment (DMA) used for the new test method.

The comparison was made by taking into consideration the bending forces measured on the first two cycles of the exciting method and the bending force measured in two distances of applied force and OP1 and OP2 on the DMA.

From the analyses of the obtained data, it was concluded that the strongest correlation between the two test methods was between the bending force of the second cycle measured on Favimat and the bending force (OP1), measured in 3 mm distance of applied force on the DMA.

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ISSN(Online) : 2319-8753
ISSN (Print) : 2347-6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

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