# Influence of Using Monofilament Yarns with Different Proportions in one/both Directions on the Stiffness of Woven Fabrics

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## Abstract:

Textile products have many chemical and natural properties, but they are characterized by two unique properties together: tensile strength and elasticity. These two properties represent two sides of the same coin that characterize textile products. Both give the textile its characteristic properties. The elasticity of the fibers and yarns and the textile's structural composition greatly affected fabric bending rigidity, which is one of the most important factors in fabric handling. Sometimes, the functional properties of the textile product require a specific rate of fabric stiffness, but this rate cannot be achieved. This is because the fabrics were woven using short or continuous textile fibers (natural or synthetic) with a limited rate of stiffness that cannot be exceeded in any way due to the natural properties of the used base material.

The research idea is enclosed in taking advantage of the high rates of available stiffness in monofilament yarns to increase the rates of fabric stiffness. At the same time, the paper aims to evaluate the effect of using monofilament yarns on the stiffness property of woven fabrics, which sheds light on directing textile fabrics to new uses, especially in industrial applications that they may not have penetrated before.

The experimental samples were varied according to fabric constructions (which were specified in the basic structures plain 1/1, twill 1/3, and satin 8), participation percentages of monofilament yarns, and participation directions of the monofilaments (warp and weft directions), with the setting of all other factors such as the fabric-set. The three main standard samples of the research were woven using polyester continuous multi-filament yarns with the standard fabric construction (one sample for each construction). The other samples were woven with different participation percentages and directions of monofilament yarns.

According to the research results, the bending lengths in the warp and weft directions were greatly positively affected by the participation rates of the monofilaments. The highest increase percentages were in the direction of the participation of monofilaments, but there were also significant increases in the bending length rates in the other direction. The increase in rates generally was also higher in the warp direction than in the weft direction for the same participation rates. The fabric samples' flexural rigidity rates increased significantly compared to standard samples. Also, the fabric flexural rigidity rates for other samples achieved higher percentages because of the increasing participation percentage rates of monofilament yarns. The fabric flexural rigidity rates for all samples achieved high rates by using plain weave 1/1, then the twill weave with an average decrease of 21%, and finally satin weave 8 with an average decrease of 32% compared to plain weave 1/1.

The importance of this research, according to its results, is that it is possible to benefit from these results in the production of fabrics with the required stiffness rate according to the appropriate specification for the final product.

## Keywords:

Stiffness, Shear rigidity bending, Bending length, Bending rigidity, Flexural rigidity, Stiffness, Monofilament.

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## 1- Introduction:

The physical properties of the normal types of fabrics are sometimes unsatisfactory for the required applications. To obtain improved, in some cases, significantly modified functional properties, they are modified in many ways. That is, the normal fabrics are chemically or physically modified. The following options are used:

### 1.1 Development of the raw materials

The development takes place here in the case of using raw material based of synthetic polymers, this item divided into:

#### 1.1.1 Production of multipolymers

If different monomers are polymerized together, multipolymers are formed. As a result, the resulting chain molecules no longer match the normal types. In this way, specific properties of fibers can be generated in a targeted manner. Copolymers are often formed. Here, monomers that have been modified by modified end groups form the chain molecules. This can improve dyeability, reduce pilling, and change electrostatic behavior, light stability, flammability, or Shrinkage-ability.

#### 1.1.2 Production of multi-component fibers

Multi-component fibers consist of at least two firmly connected polymers of different chemical and/or physical structure. Bicomponent fibers are the most common, Fig. 1 shows some of these types. There are basically three different types:

S/S types (side-by-side) Two different polymers are brought together before the spinning process and spun through a nozzle in such a way that they lie side by side. They have different properties, e.g., they shrink differently. In such a case, heat treatment would result in a bilateral, wool-like crimp.

- C/S types (core-sheath) They consist of two components contained in the spinning mass. These are brought together in the spinneret (annular nozzle) in such a way that one component is the core and the other the coating (the cloak) forms. The components have modified properties (melting point), e.g., a low-melting cladding and a thermally stable core. These are used for thermal web bonding.
- M/F types (matrix/ fibrils) These fibers consist of two incompatible, dissimilar polymers. These components are combined in the spinning mass and spun out together, with the carrier mass (matrix) receiving fibrillar inclusions from the other components. They are protected by the matrix during processing and are only separated from the matrix in the fabric/mesh by triggering a smaller differential shrinkage of the two polymers. This creates, e.g., many of the finest (microfine), slightly arched filaments that cause a fine down on the surface of the textile surface (leather imitations).

### 1.2 Development of the fabric structure

Fabric structure consists of three main elements, any development of the structure must be enclouded one of these elements, these elements are:

- Raw materials (natural, regenerated, synthetic, or mixed), spinning method, spun yarns or continues, yarn count, etc.
- Fabric constructions (plain, twill, satin, or complex weaves).
- Fabric set (number of warp and weft yarns per length unit).

The idea of the research depended on controlling the values of the stiffness rates of woven fabrics, and all previous studies have agreed that the change in the fabric construction does not change with a great rate in the fabric stiffness. It was necessary to use a fairly stiffness textile material. And because monofilament fibers are characterized by a great rate of stiffness compared to other textile fibers, they were chosen to participate in the production of experimental samples according to the technical specifications that that were designed with great care.

## 2. History

Stiffness is one of the most important properties of fabrics; it represents the rigidity of an object, which means the extent to which it resists deformation in response to an applied force. It is also a contributor to a fabric’s formability, handle, and drape. The bending rigidity increases with the increase in bending length. The bending stiffness characteristics of fabrics are determined by the structure of the fabric itself and the structure of the constituent yarns. A stiff yarn, like a wire, makes a fabric stiff regardless of the weave.

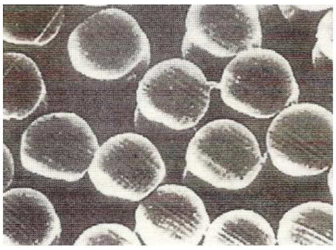
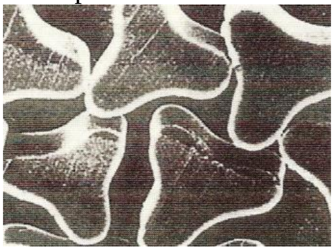
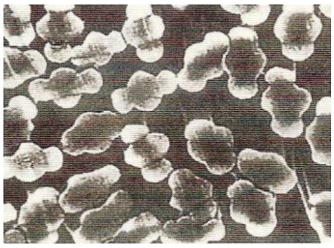
### 2.1 Fabric structure

The traditional textile materials can be characterized as either natural or synthetic fibers. The natural materials (except silk) are available exclusively as spun staple products, whereas the synthetic filaments are often available in more formats, with monofilament yarns, multifilament yarns, and staple fibers by either cutting or stretch-breaking processes. The majority of synthetic continuous filament (CF) yarns are made of extruded natural or synthetic fibers through the spinneret. These filament yarns can be in general divided into:

- Monofilament yarn is extruded relatively thick as a single filament yarn.
- Multifilament yarn is extruded in the form of multiple filament fibers.

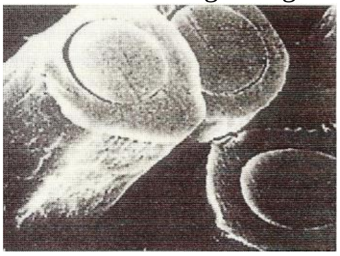
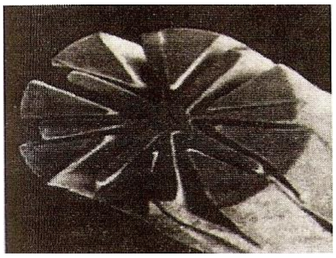
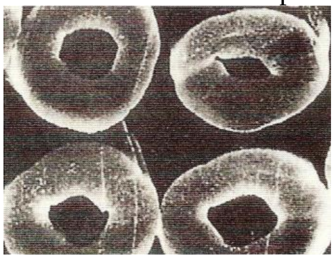
Continuous filament yarns are sometimes required to be intermingled or twisting process to hold the multifilament yarn together. When fibres have a cross-section that is ribbon-like, that is with one dimension smaller than the other, the fibre stiffness is determined by the smaller dimension as the fibre tends to bend in this direction when stressed. Fibres that have indented shapes such as star or trilobal cross-sections in which the maximum diameter is roughly the same in all directions are nearly as stiff as a fibre whose diameter is the same as their greatest dimension but have a lower mass per unit length and hence thickness value owing to the indentations. The strength of a fibre, however, is determined by the amount of material in the cross-section and not how it is arranged. These factors mean that when comparing fibres of different cross-section their thickness values are not necessarily a guide to their properties. Similarly, fibres of different densities but of the same thickness value will have different diameters (assuming that their cross-sectional shape is the same)/1/.

Special cross-section shape

Round Trilobal Multilobal

change the gloss effect and the handle increase moisture transport

Core-Sheath type Matrix-Fibril type Hollow fiber

Biocomponent fibers

Fig. 1: Different types of cross-section synthetic fibers /2/

Changing the fiber cross-section as represents in Fig. 1 leads to a change in the optical, textile or physiological properties of the textile surface. Trilobal and multilobal fiber cross-sections make the fibers softer and more like natural silk in terms of luster and feel. An increased gloss effect is achieved through triangular cross-sections. Hollow fibers enable a high level of air inclusion, have a very good bulking power and good heat retention with low weight and are therefore used as filling fibers. Also, a four-channel fiber with a large surface specially developed for sports supports the body's cooling process and ensures that moisture is transported away from the skin's surface (Dracon Coolmax).

However, using flexible strands, it can produce fabrics with a wide range of stiffness, depending on the fabric structure. In this study, analytical relations have been found between fabric stiffness (or flexural rigidity) and various fabric structural parameters. Yarn (or fiber) diameter is the most important structural property of a fabric to affect its stiffness. As the fiber or yarn diameter is increased, the fabric stiffness increases.Certainly, there is a relationship between the stiffness of textile fabrics (or flexural stiffness) and the various textile structural factors, including the structural nature of monofilament fibers, in addition to the textile structural structures, although the rate of their effect on the difference in stiffness results according to previous studies was limited /3/.

**2.2 Fabric stiffness**

An analysis of fabric hand has been described by the ASTM as being composed of eight components: compressibility, flexibility, extensibility, density, resilience, surface contour, surface friction, and thermal properties. The measurement of these properties does not give one an evaluation of hand. Sueo Kawabata approached the task of providing a single value for hand by starting with the development of instruments that would be capable of evaluating the desired fabric properties /4/.

The term "handle," given to properties assessed by touch or feel, depends upon the subjective assessment of the fabric by a person. Terms such as smooth, rough, stiff, or limp depend strongly on the type of fabric being assessed. A form of the cantilever stiffness by Shirley (the stiffness apparatus) is often used as a measure of a fabric's stiffness. In the test, a horizontal strip of fabric is clamped at one end, and the rest of the strip of fabric to bend to a fixed angle under its own weight. The length of the fabric required to bend to this angle is measured and is known as the bending length. This is shown diagrammatically in Fig. 2.

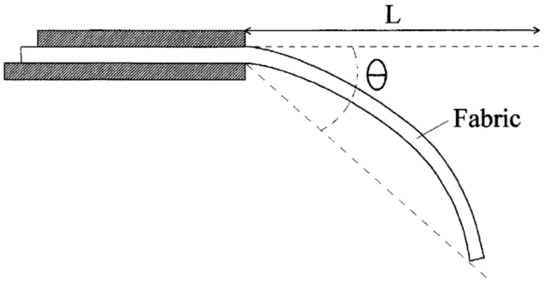



Fig. 2: Bending length (Peirce’s cantilever) test / 5, 6/

When the tip of the specimen reaches a plane inclined at 41.5° below the horizontal, the overhanging length is then twice the bending length. This angle is used in the Shirley apparatus to increase the sensitivity of the length measurement, and the slide on this instrument is directly calibrated in centimetres.

The bending length is related to the angle that the fabric makes to the horizontal by the following relation:

$$C = L\left(\frac{\cos\frac{1}{2}\theta}{8\tan\theta}\right)^{1/3}$$

where $C = bending\ length\ (mm)$,
$L = length\ of\ fabric\ projecting$,
$\theta = angle\ fabric\ bends\ to$.

The mean bending length for warp and weft is calculated. The higher the bending length, the stiffer is the fabric /6/.

The relationship among the length of the overhanging strip, the angle that it bends to and the flexural rigidity, G, of the fabric is a complex one which was solved empirically by Peirce to give the formula:

$$G = ML^3\left(\frac{\cos\frac{1}{2}\theta}{8\tan\theta}\right)$$

Where: $M = fabric\ mass\ per\ unit\ area\ (g/m^2)$.

The flexural rigidity is the ratio of the small change in bending moment per unit width of the material to the corresponding small change in curvature:

$$G = M \times C^3 \times 9.807 \times 10^{-6} \mu Nm.$$

## 3. Methodology:

### 3.1 Analysis of the Problem

The research problem is limited to studying the effect of the participation of monofilament yarns in the stiffness properties of woven fabrics and studying the extent of their participation in different proportions in the warp and weft directions. In addition to that, maintaining the appearance of woven fabrics to a large extent.

### 3.2 Theory of research method:

The search method depends on:

- Theoretical studies related to the physical and natural properties of the structural elements of the proposed raw materials.
- Selection the warp and weft yarn material that will contribute well to the different stiffness rates of the woven fabrics
- Setting the variables structural specifications elements that achieve the objectives of the research.
- Equipping the weaving machine and setting the tension of the yarns, which have different physical properties used in the research.

### 3.3 Weaving of Standard Experiment Samples

This important part of the research was identified in weaving experimental samples with different elements of fabric structures. The fabric structures were limited to plain weave 1/1, twill 1/3, and satin 8 weaves.

### 3.4 Laboratory Measurements

The laboratory measurements were limited to stiffness of fabrics by using the cantilever test (according to ASTM D1388), in which a strip of fabric is bent under its own weight.

## 4. Experiments:

The experimental work has been achieved on the narrow weaving machine model NF53 (VLAL) (Jacob Müller Company) equipped with 18 harness frames, and with a fabric width of up to 210 mm.

**The experimental works were divided into two phases:**

1- Weaving of experimental samples.
2- Laboratory measurements.

### 4.1 Weaving of experimental samples:

The standard specimens of the experimental samples were woven according to the specifications, as represented in Table 1.
sub-specification

**The main elements of the woven fabric structure variables were:**

1- Fabric constructions:
- Plain weave 1/1.
- Twill weave 1/3.
- Satin weave 8.

2- Warp and weft yarn material:
- Textured Polyester (CF), and Monofilament Polyamide (denier 200).
- The arrangement systems of the warp and weft yarns were as represented later in Tables 1 and 2.

3- Warp yarns density: 32 yarns/cm.
4- Wefts density: 20 shots/cm (double wefts were inserted in a shot).

| Material | Item / Yarn | Count tex | $\varepsilon$ - $F_{max}$ % | $F_{max}$ N | $F_{max}$ cN/tex |
|---|---|---|---|---|---|
| Material | PES (Texture yarn) | 22.38 | 21.17 | 7.80 | 34.86 |
| | PA (Monofilament) | 22.23 | 25.20 | 14.42 | 64.87 |

| | Fabric-Set / Construction | Warp density [yarn/cm] | | Weft density [weft/cm] | | Yarns Arrangement in a fabric repeat | |
|---|---|---|---|---|---|---|---|
| | | PES | PA | PES | PA | Warp PES : PA | Weft PES : PA |
| Fabric | Plain 1/1 (P 1/1) | 32 | - | 20 | - | - | |
| | Twill 1/3 (T 1/3) | 32 | - | 10 | 10 | - | 1:1 |
| | Satin 8 (S 8) | 16 | 16 | 20 | - | 1:1 | - |
| | | 32 | - | - | 20 | - | - |
| | | - | 32 | 20 | - | - | - |
| | | 16 | 16 | 10 | 10 | 1:1 | 1:1 |
| | | 16 | 16 | - | 20 | 1:1 | - |
| | | - | 32 | 10 | 10 | - | 1:1 |
| | | - | 32 | - | 20 | - | - |

Table 1: Specifications of the structural elements for the experimental samples

**4.2 Laboratory Measurements**

The laboratory measurements have been performed according to standard procedures recommended by the A.S.T.M (American Standards on Textile Materials). Th2e measurements were limited to yarns and wefts crimp percentage, fabric weight, and finally bending length in both directions of the fabric samples.

**The following data shows the details of the measurements:**

- Yarns crimp percentage (ASTM D3883-04R20),
- Mass per unit area (fabric weight) (ASTM D3776M-20),
- Fabric stiffness (bending length) (ASTM D1388-18).

## 5. Results and discussions

The data mentioned in Table 2 show the results of the laboratory tests performed on the experimental samples and the results which were found by using technical equations for all woven structures according to the specifications' elements shown in Table 1.

**5.1 The description of the research results**

These results indicate the samples' weight in grams per square meter, the bending lengths of the samples in both directions, and the crimp percentage rates for warp and weft yarns, all in accordance with the previously mentioned standard specifications.

In addition, other data were calculated through mathematical equations, which were determined in:

- The participation percentages of the monofilament yarns in the experimental samples in both directions.
- The flexural rigidity in the warp and weft directions, was calculated by the given values of the bending lengths.
- In addition to all, the average values of fabric flexural rigidity, have been calculated.

Table data indicate that there was a negligible change (less than 1.45%) in the samples' weight between the heaviest and lightest samples, independently for each fabric construction. This is because, despite the use of yarns being different in physical properties, they have the same yarns count, even the difference in thickness between the multifilament polyester and the monofilament polyamide yarns, is related to the difference in fiber density and yarns physics. On the other hand, just only one fabric set has been used for all research samples.

The samples in Table 2 were arranged in ascending order according to the results of the final fabric flexural rigidity rates of the woven samples measured in micronewtons meter (μN·m) for each fabric construction independently, to accurately indicate the impact of the various research variables on the results. Overall, it was possible to identify the research variables in three main points:

| Fabric Construction | | Sample Nr. | Warp Density [yarn/cm] | | Weft Density [weft/cm] | | Warp Crimp [%] | Weft Crimp [%] | Weight percentages of Mono PA [%] | | | Fabric Weight [gr/m²] | Fabric Weight w [mg/cm²] | Bending Length c [cm] | | Flexural Rigidity G= wc³ [mg.cm] | | Flexural Rigidity [µN.m] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PES | PA | PES | PA | | | Warp | Weft | Fabric | | | Warp | Weft | Warp | Weft | Fabric |
| Plain Weave | P 1/1 | 1 | 32 | - | 20 | - | 10.7 | 8 | - | - | - | 175.43 | 17.543 | 2.04 | 1.86 | 148.93 | 112.89 | **12.720** |
| | | 2 | 32 | - | 10 | 10 | 11.6 | 7.5 | - | 50 | 27.4 | 175.30 | 17.530 | 2.75 | 5.02 | 364.57 | 2217.64 | **88.207** |
| | | 3 | 16 | 16 | 20 | - | 9.5 | 9.5 | 50 | - | 22.2 | 176.18 | 17.618 | 5.82 | 2.46 | 3473.19 | 262.28 | **93.630** |
| | | 4 | 32 | - | - | 20 | 12.5 | 7.0 | - | 100 | 54.3 | 175.17 | 17.517 | 3.40 | 7.21 | 688.50 | 6565.56 | **208.572** |
| | | 5 | - | 32 | 20 | - | 9.0 | 10.2 | 100 | - | 44 | 176.19 | 17.619 | 8.36 | 3.22 | 10294.3 | 588.23 | **241.402** |
| | | 6 | 16 | 16 | 10 | 10 | 10 | 9.0 | 50 | 50 | 50 | 175.76 | 17.576 | 6.14 | 5.63 | 4068.49 | 3136.56 | **350.439** |
| | | 7 | 16 | 16 | - | 20 | 10.4 | 8.4 | 50 | 100 | 77.5 | 175.19 | 17.519 | 6.2 | 8.82 | 4175.23 | 12020.18 | **694.968** |
| | | 8 | - | 32 | 10 | 10 | 8.4 | 9.5 | 100 | 50 | 72.1 | 174.81 | 17.481 | 9.32 | 5.93 | 14151.6 | 3645.22 | **704.587** |
| | | 9 | - | 32 | - | 20 | 8.0 | 8.6 | 100 | 100 | 100 | 173.68 | 17.368 | 11.21 | 10.1 | 24466.0 | 17894.12 | **2052.606** |
| Twill Weave | T 1/3 | 10 | 32 | - | 20 | - | 7.2 | 4.6 | - | - | - | 169.90 | 16.990 | 1.93 | 1.72 | 122.14 | 86.45 | **10.080** |
| | | 11 | 32 | - | 10 | 10 | 8 | 4.1 | - | 50 | 27.4 | 169.70 | 16.970 | 2.56 | 4.71 | 284.72 | 1773.20 | **69.704** |
| | | 12 | 16 | 16 | 20 | - | 6 | 6.2 | 50 | - | 22.2 | 170.73 | 17.073 | 5.45 | 2.33 | 2763.73 | 215.96 | **75.789** |
| | | 13 | 32 | - | - | 20 | 8.9 | 3.6 | - | 100 | 54.3 | 169.59 | 16.959 | 3.19 | 6.77 | 550.51 | 5262.13 | **166.968** |
| | | 14 | - | 32 | 20 | - | 5.5 | 6.7 | 100 | - | 44 | 170.57 | 17.057 | 7.82 | 3.00 | 8156.68 | 460.53 | **190.132** |
| | | 15 | 16 | 16 | 10 | 10 | 6.5 | 5.5 | 50 | 50 | 50 | 170.14 | 17.014 | 5.78 | 5.27 | 3285.46 | 2490.26 | **280.601** |
| | | 16 | 16 | 16 | - | 20 | 6.9 | 4.9 | 50 | 100 | 77.5 | 169.58 | 16.958 | 5.83 | 8.25 | 3360.28 | 9522.07 | **554.910** |
| | | 17 | - | 32 | 10 | 10 | 5 | 6 | 100 | 50 | 72.1 | 169.27 | 16.927 | 8.73 | 5.55 | 11261.9 | 2893.67 | **560.015** |
| | | 18 | - | 32 | - | 20 | 4.5 | 5.1 | 100 | 100 | 100 | 168.15 | 16.815 | 10.42 | 9.36 | 19023.6 | 13788.55 | **1588.822** |
| Satin Weave | S 8 | 19 | 32 | - | 20 | - | 4.4 | 2.8 | - | - | - | 166.29 | 16.629 | 1.82 | 1.66 | 100.25 | 76.07 | **8.567** |
| | | 20 | 32 | - | 10 | 10 | 5.2 | 2.4 | - | 50 | 27.4 | 166.20 | 16.620 | 2.45 | 4.49 | 244.41 | 1504.39 | **59.485** |
| | | 21 | 16 | 16 | 20 | - | 3.2 | 3.4 | 50 | - | 22.2 | 166.22 | 16.622 | 5.21 | 2.22 | 2735.49 | 181.87 | **69.193** |
| | | 22 | 32 | - | - | 20 | 6.1 | 1.9 | - | 100 | 54.3 | 166.08 | 16.608 | 3.04 | 6.49 | 466.61 | 4540.08 | **142.783** |
| | | 23 | - | 32 | 20 | - | 2.8 | 3.9 | 100 | - | 44 | 166.14 | 16.614 | 7.47 | 2.88 | 6925.22 | 396.87 | **162.634** |
| | | 24 | 16 | 16 | 10 | 10 | 3.7 | 2.8 | 50 | 50 | 50 | 165.74 | 16.574 | 5.48 | 5.03 | 2333.55 | 2109.20 | **217.639** |
| | | 25 | 16 | 16 | - | 20 | 4.1 | 2.3 | 50 | 100 | 77.5 | 165.27 | 16.527 | 5.55 | 7.88 | 2804.90 | 8086.61 | **467.208** |
| | | 26 | - | 32 | 10 | 10 | 2.5 | 3.2 | 100 | 50 | 72.1 | 164.99 | 16.499 | 8.33 | 5.30 | 9536.55 | 2456.31 | **474.795** |
| | | 27 | - | 32 | - | 20 | 2.1 | 2.4 | 100 | 100 | 100 | 163.97 | 16.397 | 10.08 | 9.12 | 16793,5 | 12437.84 | **1417.792** |

Table 2: The different values of yarn crimp, weight, bending length, and flexural rigidity for all fabric constructions

- The difference in the fabric constructions (plain, twill, and satin weaves).
- The difference in the participation rates of the monofilament polyamide yarns in the fabric (0%, 22.2%,27.5%, 44%, 50%,54.3%, 72.1%, 77.5%, and 100%).
- The participation direction of the monofilament polyamide yarn, whether in the longitudinal or horizontal direction (0%, 50%, and 100%).

Fig. 3 shows a clear interpenetration between the participation percentages of monofilament yarns on the first hand and the direction of their participation direction on the other hand in the experimental samples, whether it is in the longitudinal or horizontal directions of the samples. Anyway, all that greatly affects the stiffness rates of the samples.

**5.2 Analysis of the Influence of the research's variables on the results**

The research aims to evaluate the effect of using monofilament yarns on the stiffness property of woven fabrics, which sheds light on directing textile fabrics to new uses, especially in industrial applications that they may not have penetrated before.

Therefore, the following items show the effect of various factors on the studied woven fabrics' stiffness as follows:

**5.2.1 The influence of research variables on the rates of bending length in the warp direction**

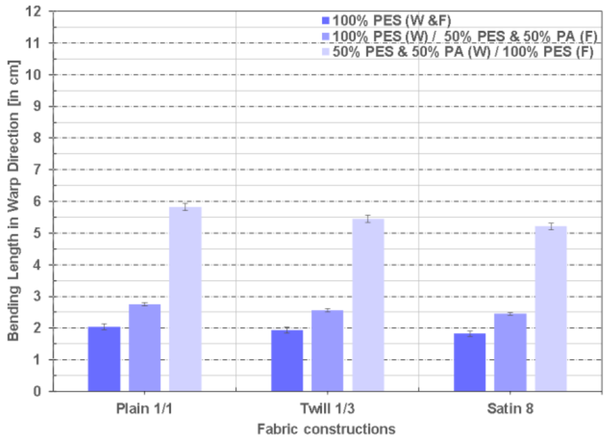
The bending length in the warp direction values of the woven fabrics varied with the differences in the fabric constructions, percentages participation of monofilament, and the direction of their participation, as illustrated in Fig. 3A, B, and C.

The highest average values of bending length were achieved by using plain weave 1/1, followed by twill weave 1/3, and the lowest values were achieved by using satin weave 8. This successive decrease in rates from plain to twill to satin weaves is due to the decrease in the number of intersections in the longitudinal direction from 4 times (4 intersections) for plain weave 1/1 to twice times (two intersections) for twill weave 1/3 compared with satin weave 8 (one intersection), all that with the same number of wefts (8 wefts), which interlaced with a similar warp yarn in the longitudinal direction. That leads to a decrease in the contact surfaces7 and, consequently, a decrease in the friction rates between the warp and weft yarns for twill weave 1/3, and a greater decrease for satin 8, compared to the plain weave 1/1, which increases the yarns freedom and thus causes a successive decrease in rates of the bending length in the warp direction for the three fabric constructions.

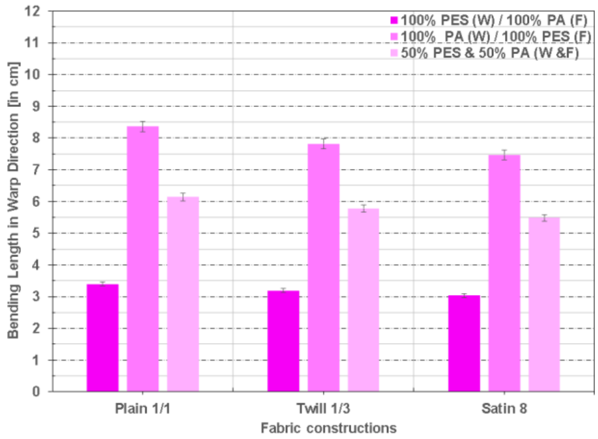
According to the test results in Table 2 and Figure 3, the standard samples (No. 1, 19, 10), which were woven by using just polyester multifilament for warp and weft yarns achieved normal bending length values in the warp direction. But using 50% of the weft yarns of monofilament yarns caused the increase of bending length in the warp direction rates for all woven samples (No. 2, 11, 20) with an increased average of 34% compared to the standard woven samples which were woven without using monofilament yarns. While utilizing 50% of monofilament for warp yarns, the rates of bending length increased in the warp direction for all woven samples (No. 3, 12, 21), with an increased average of 185% compared to the standard woven samples (No. 1, 10, 19).

Using 100% of the weft yarns of monofilament yarns caused the increase of bending length in the warp direction rates for all woven samples (No. 4, 13, 22) with an increased average of 66% compared to the standard woven samples, but by using the same percentage of 100% of monofilament yarns for the warp yarns, the rates of bending length in the warp direction increased more for all woven samples (No. 5, 14, 23) with an increased average of 309%. On the other hand, the increased rates were decreased to 201% more than standard samples by using 50% of the warp and weft yarns of monofilament yarns for all samples (No. 6, 15, 24), compared to the standard samples (No. 1, 19, 10).

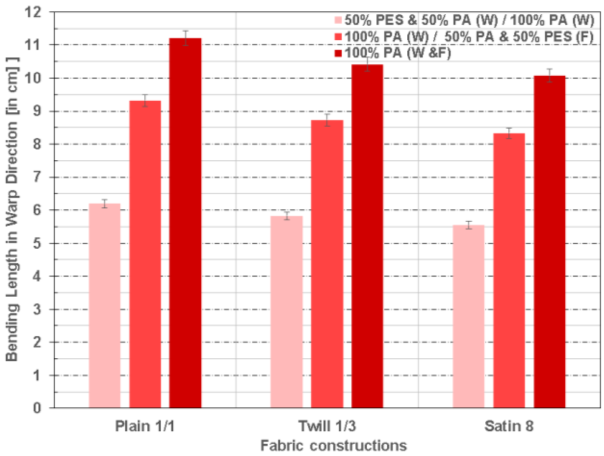
Utilization of 50% of the warp yarns, in addition to 100% of the wefts of monofilament yarns caused the increase of bending length in the warp direction rates for all woven samples (No. 7, 16, 25), with an increased average of 204% compared to the standard woven samples. The use of 100% of the warp yarns, in addition to 50% of the wefts of the monofilament yarns caused the increase of bending length in the warp direction rates for all weaving samples (No. 8, 17, 26), with an average increase of 356%. Finally, the highest rates of bending length in the warp direction were achieved with an average percentage of 446% compared to standard samples (No. 1, 19, 10), by using 100% of warp and weft yarns from monofilament yarns, for the woven samples (No. 9, 18, 27).




A




B




C

Fig. 3: The relation between fabric construction elements and bending length in the warp direction

**5.2.2 The influence of research variables on the rates of bending length in the weft direction**

The results' values of the bending length in the weft direction for the experimental samples were similar in the trend of increase and decrease to the values of the bending length in the warp direction for the correspondent samples that are identical to them in participation percentages of monofilament yarns for the same test direction, except that they are generally less the values in the warp direction as shown in Table 2. The highest average values of bending length in the weft direction were achieved by using plain weave 1/1, followed by twill weave 1/3, and the lowest values were achieved by using satin weave 8.

That successive decrease in rates from plain to twill to satin weaves is due to the decrease in the number of intersections in the horizontal direction, as discussed before in the results of the bending length in the warp direction. Also, the results of the bending length in the weft direction are less than similar in the warp direction, due to the weaving method on the narrow weaving machines where there are two tangent parallel wefts with each other in the same shed, just separated in the right selvage edge. That gives the wefts greater resistance to crimp under the influence of the exchanged tension with the warp yarns, this relative freedom makes them have less resistance to bend compared to the bending in the warp direction.

According to the test results in Table 2 and Figure 4, the standard samples (No. 1, 10, 19), which were woven by using just polyester multifilament for warp and weft yarns achieved normal bending length values in the weft direction. Using 50% of the weft yarns of monofilament yarns caused the increase of bending length in the weft direction rates for all woven samples (No. 2, 11, 20) with an increased average of 171% compared to the standard woven samples. But the increased rates were decreased to 34% more than standard samples by using 50% of monofilament for warp yarns of monofilament yarns for all samples (No. 3, 12, 21). Utilization of 100% of the weft yarns of monofilament yarns caused the increase of bending length in the weft direction rates for all woven samples (No. 4, 13, 22) with an increased average of 291% compared to the standard woven samples. But the values were decreased to 74% more than standard samples (No. 1, 19, 10) by using 100% of monofilament yarns for the warp yarns for all samples (No. 5, 14, 23). The rates of bending length in the weft direction increased again to 204% by using 50% of the warp and weft yarns from monofilament yarns for all samples (No. 6, 15, 24), compared to the standard samples.

Using 50% of the warp yarns, in addition to 100% of the wefts of monofilament yarns caused the increase of bending length in the weft direction rates for all woven samples (No. 7, 16, 25), with an increased average of 376% compared to the standard woven samples. The use of 100% of the warp yarns, in addition to 50% of the wefts of the monofilament yarns decreased the bending length in the weft direction rates for all weaving samples (No. 8, 17, 26), with an increased average of 220% more than standard samples. Finally, the highest rates of bending length in the weft direction were achieved with an average percentage of 446% compared to standard samples by using 100% of warp and weft yarns from monofilament yarns, for the woven samples (No. 9, 18, 27).

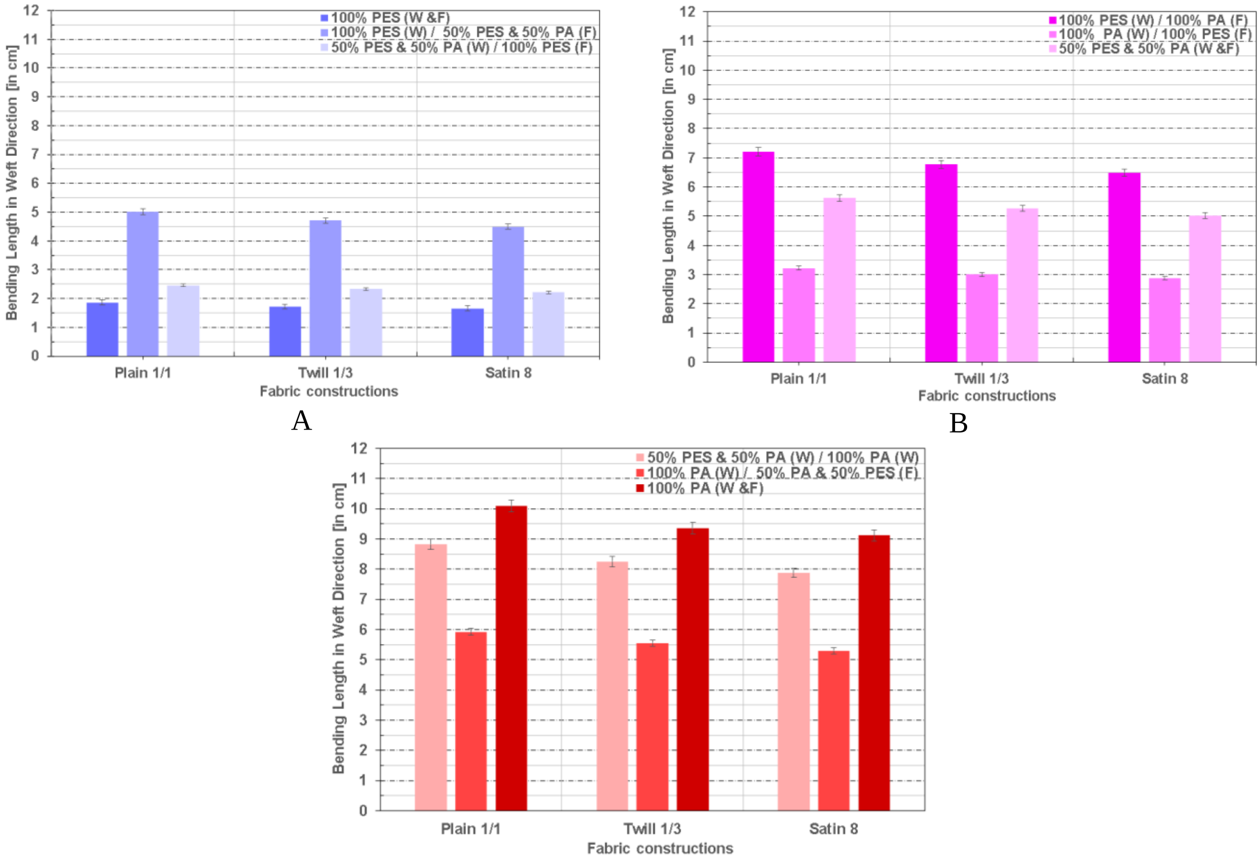



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Fig. 4: The relation between fabric construction elements and bending length in the weft direction

**5.2.3 The influence of research variables on the rates of the fabric flexural rigidity**

Table 2 shows the flexural rigidity rates of the experimental samples in the warp and weft directions, with the initial data by which the flexural rigidity rates of the experimental fabric samples were calculated by using the mathematical method, as previously described in a literature review. It was found that it is more useful to discuss the bending stiffness of the fabric than the flexural rigidity in the warp and weft directions, due to the use of monofilaments in some samples included in one direction only without the other. Therefore, it was found that it is better to discuss the result of the total result of the flexural rigidity of the woven samples.

The main variables that affected the results of fabric flexural rigidity can be divided into two important factors:

**5.2.3.1 Woven fabrics' constructions**

The difference in the woven fabric constructions significantly affects the fabric flexural rigidity rates, as shown in Table 2 and Fig. 5. The plain weave 1/1 woven samples had the highest rates of fabric flexural rigidity, while the average was 21% lower with twill weave 1/3 and 32% lower with Atlas weave 8. This decrease in fabric flexural rigidity rates is attributed to the decrease in the number of intersections in the longitudinal and horizontal directions from 32 intersections for plain weave 1/1 to 16 intersections for twill weave 1/3 compared with satin weave 8 (8 intersections) for the same flat area. That leads to a decrease in the contact surfaces and, consequently, a decrease in the friction rates between the warp and weft yarns for twill weave 1/3, and a greater decrease for satin 8, compared to the plain weave 1/1, which increases the yarns freedom and thus causes a successive decrease in rates of the flexural rigidity of the different fabric constructions.

**5.2.3.2 The participation percentage of monofilament yarns**

There were three patterns for the presence of monofilament yarns in the experimental samples, which were:

**A. No participation at all**

In accordance with the test results shown in Table 2 and Figure 5A, the standard samples, which were woven using polyester multifilament only for warp and weft yarns, achieved normal values in the flexural rigidity rates of the experimental samples (No. 1, 19, 10).

**B. Partial participation**

Low participation in one direction

The participation rate of monofilament yarns represented 50% of the number of warp or weft yarns, as shown in Table 2 and Figure 5A. The fabric flexural rigidity achieved an average equal to 79.54 µNm, with the participation of monofilament in the warp yarns, while the average was 72.47 µNm, with the participation of the same percentage in the weft direction. That was, although the weight of monofilament wefts percentage was an average equal to 27.4% of the samples' weights (No. 2, 11, 20), and higher than their similar samples which used monofilament yarns in the warp direction with average weight equal to 22.2% of the samples (No. 3, 12, 21). These results confirm that the participation of monofilament yarns in the warp direction achieved higher results than their participation in the weft direction, with the same fabric specifications.

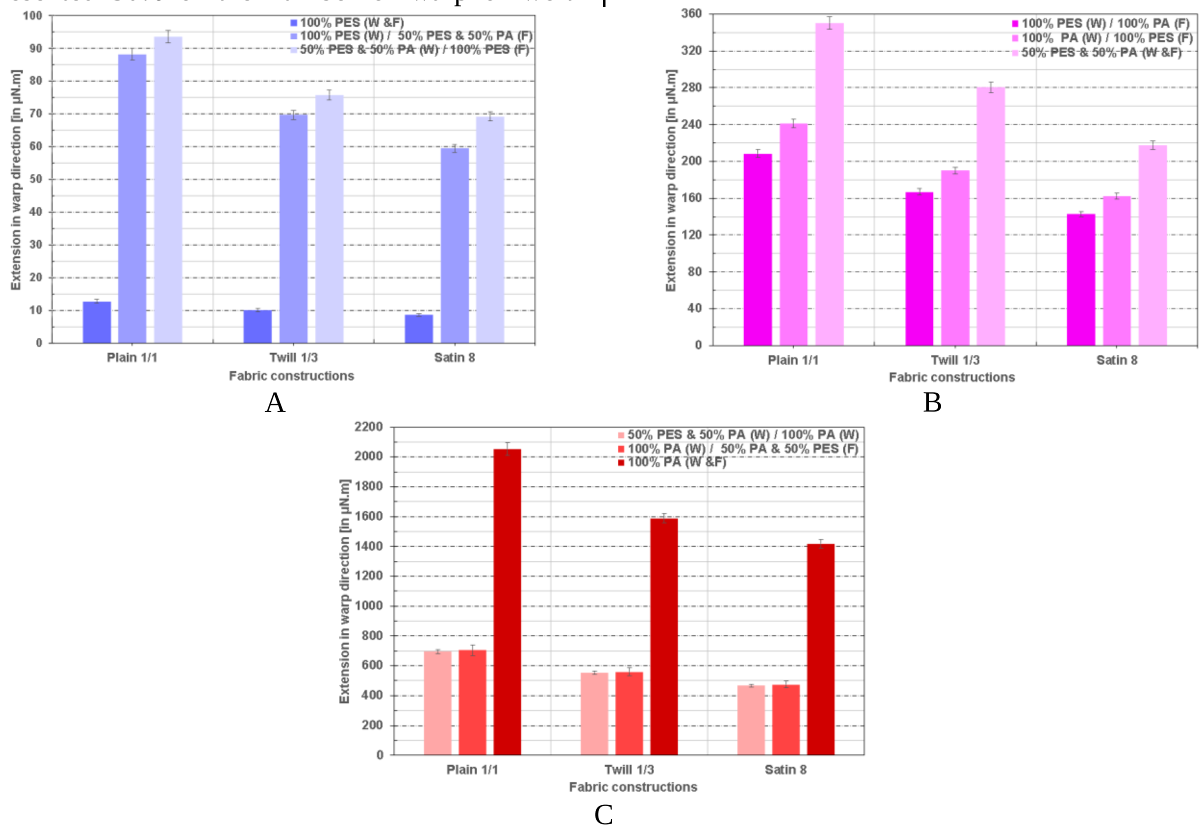


Fig. 5: The relation between fabric construction elements and the fabric flexural rigidity

**Average participation in one or both directions**

The participation rates of monofilament yarns are represented as shown in Table 2 for samples and Figure 5B as follows:

- 100% of the number of wefts (54.3% of the sample's weight) for the samples (No. 4, 13, 22), or 100% of the number of warp yarns (44% of the sample's weight) for the samples (No. 5, 14, 23).
- 50% of the number of warp and 50% of the wefts (50% of the sample's weight) for the samples (No. 6, 15, 24).

With the participation of 100% of the number of wefts, the fabric flexural rigidity achieved an average equal to 172.77 µNm, while the average result was 198.06 µNm with the participation of the same percentage in the warp direction. The average rate of the fabric flexural rigidity was increased to 282.89 µNm, by using 50% of the number of warp and 50% of the wefts. The participation of monofilament yarns in the warp direction achieves higher results than their participation in the weft direction, but the average results of the fabric flexural rigidity were increased more by using monofilament yarns in both fabric directions.

**High participation in both directions**

The participation rate of monofilament yarns is represented as shown in Table 2 for samples and Figure 5C:

- 50% of the number of warp and 100% of the wefts (77.5% of the sample's weight) for the samples (No. 7, 16, 25).
- 100% of the number of warp and 50% of the wefts (72.1% of the sample's weight) for the samples (No. 8, 17, 26).

With The participation of 50% of the number of warp yarns, and 100% of the wefts, the fabric flexural rigidity achieved an average equal to 575.36 µNm, while the average result was 579.80 µNm with the participation of 100% of the number of warp yarns and 50% of the wefts.

It was concluded from these results, that the increase of monofilament yarns' percentage from 49.43% of the sample weight (average participation) to 74.8% (high participation) affected the increase in the fabric flexural rigidity by an average increase of 164.37%.

**C. Entirely monofilament yarns**

The woven samples (No. 9, 18, 27) were woven by using monofilament yarns completely for the warp and weft yarns as shown in Table 2 and Figure 5C. The fabric flexural rigidity achieved an average equal to 1686.41 µNm for all fabric constructions. It was concluded from this result, that the increase of monofilament yarns' percentage from 74.8% of the sample weight (high participation) to 100% affected the increase in the fabric flexural rigidity by an average increase of 192.74%.

## 6. Conclusions:

A certain rate of stiffness is sometimes required to suit the functional characteristics of the desired application in some woven fabrics. certainly, a large proportion of fabrics that are woven from spun or continuous fibers (natural or synthetic) achieve a certain rate of stiffness, which can't be increased owing to the specific natural and physical properties of their materials. Therefore, the research idea tended to take advantage of the higher rates of available stiffness in monofilament yarns, to increase the stiffness rates of woven fabrics by using the standard fabric constructions represented in the plain 1/1, twill 1/3, and satin 8 weaves. The experimental samples were 27 samples (9 samples for each fabric construction), using three variables represented by three fabric constructions, three participation percentages of monofilament yarns (0%, 50%, 100%), and two participation directions of the monofilaments (warp and weft directions) with the setting of all other factors such as the number of warp and weft yarns. The three main standard samples of the research were woven using polyester continuous multi-filament yarns with the standard fabric construction (one sample for each construction), and the other samples were woven in a technical economical method to reduce the rates of waste in production. According to the research results, the bending lengths in the warp and weft directions were greatly positively affected by the participation rates of the monofilaments. Surely, the highest increase percentages were in the direction of the participation of monofilaments, but there were also significant increases in the bending length rates in the other direction. The increase in rates generally was also higher in the warp direction than in the weft direction for the same participation rates. The fabric samples flexural rigidity rates increased significantly, for example, the rate of increasing percentage was 593% when participating with 50% monofilament yarns in the weft direction only, and 661% when participating with 50% monofilament yarns in the warp direction only, compared to standard samples. Also, the fabric flexural rigidity rates for other samples achieved higher percentages by the increasing of participation percentage rates of monofilament yarns. The fabric flexural rigidity rates for all samples achieved high rates by using plain weave 1/1, then the twill weave with an average decrease of 21%, and finally satin weave 8 with an average decrease of 32% compared to plain weave 1/1.

From the previous explanation of the research's importance, and from an applied point of view, it is possible to benefit from its results in the production of fabrics with various stiffness rates, according to the appropriate specification for the final product, especially in technical fields.

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