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INVESTIGATION OF THE BENDING BEHAVIOUR OF WOVEN SPACER FABRICS

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Abstract: *Spacer fabrics are a category of 3D textiles and consist of two distinct fabrics which are connected together by spacer (pile) yarns. Spacer fabrics are produced by weaving, warp knitting and weft knitting systems and have many applications in different industries. The aim of this study was the production of woven spacer fabrics and analysis of their bending behavior. Thereafter, six different spacer fabrics were produced based on two variables: spacer yarn pattern and spacer yarn density. The resistance to bending of the spacer fabrics was measured based on the standard test method for evaluation of the fabric stiffness, by the circular bend procedure. In this regard, the maximum bending load and bending energy of spacer fabrics were recorded. The results showed that resistance to bending in spacer fabrics with V pattern of spacer yarns in the structure and also spacer fabrics with full threading of spacer yarns in the weaving reed was more than other kinds of spacer fabrics. By increasing the pile density and the number of spacer yarns, the fabric's bending became more difficult. Statistical analysis of results at the confidence range of 95%, also revealed that the spacer yarn pattern and spacer yarn density have significant effect on bending resistance of spacer fabrics.*

Key words: *Spacer Fabric, Weaving, Bending Load, Bending Energy, Weave Structure.*

1. INTRODUCTION

Spacer fabrics are a kind of three-dimensional fabrics where two surface layers are connected to each other by means of spacer (pile) yarns. Spacer fabrics are commonly produced by the circular knitting process (weft-knitted spacer fabrics), double needle bar warp knitting process (warp-knitted spacer fabrics) or weaving process (woven spacer fabrics). However, woven spacer fabrics show exclusive mechanical properties, such as higher stiffness, strength and dimensional stability, than knitted spacer fabrics and are used for technical applications such as aerospace, automotive and medical industries and so on [1,2,3]. Spacer fabrics are characterized by their special mechanical properties compared to two-dimensional textiles, which also depends on the properties of the spacer yarns connecting the surface layers [4,5]. Many researches have been performed to investigate the mechanical properties of spacer fabrics.

Yip et al (2007), investigated the bending and compression behavior of warp knitted and weft knitted spacer fabrics using monofilament and multifilament as the spacer yarns. The results showed that spacer fabrics produced by monofilament spacer yarns presented better resistance against compression and bending deformations, because monofilaments are less flexible than multifilaments. It was also revealed that the angle of the spacer yarns in the fabric structure affects the mechanical properties of the spacer fabrics [6].

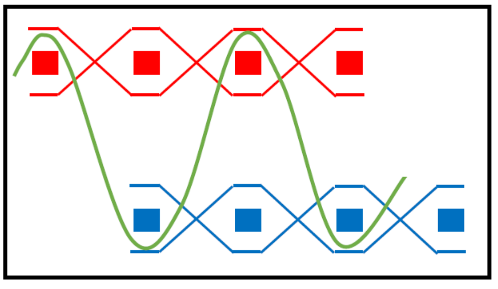
Liu et al (2012), tried to find out the effect of structural parameters on compression behavior of warp knitted spacer fabrics used for cushioning applications. In this regard, it was declared that by increasing the number of underlaps in the fabric, the angle of spacer yarns and therefore, the compressional resistance of the fabric decreases [7].

The aim of this study is to produce woven spacer fabrics with various structural parameters and considering the effect of fabrics' structural parameters on their bending behavior.

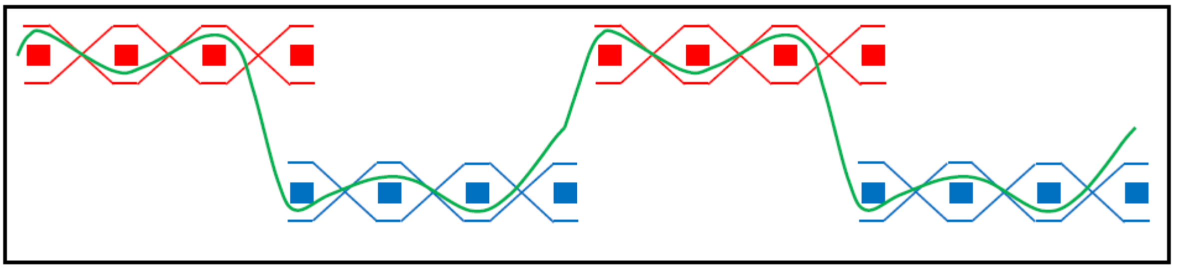
2. EXPERIMENTAL

2.1 Sample preparation

The spacer fabrics were produced by weaving mechanism, using a shuttle loom. In this regard, six different spacer fabrics were produced by utilization of polyester ($10_{/3}$ Ne) as warp and weft yarns, and cotton ($12_{/3}$ Ne) as spacer yarns. Variables of the woven spacer fabrics consist of spacer yarn pattern (V pattern and W pattern) and spacer yarn density (full threading of spacer yarn (D-1), every other one theading of spacer yarn (D-01), and every other two threading of spacer yarn (D-001)), as shown in Figure 1 and Figure 2, respectively. The plain weave pattern was chosen as the pattern of both layers. It should be noted that the spacer yarn is also a group of warp yarns that connects the upper and lower layers of the spacer fabric.

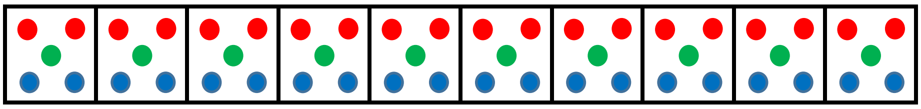


a) V pattern of spacer fabric

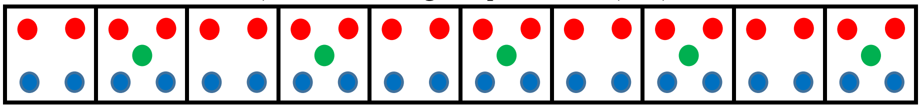


b) W pattern of spacer fabric

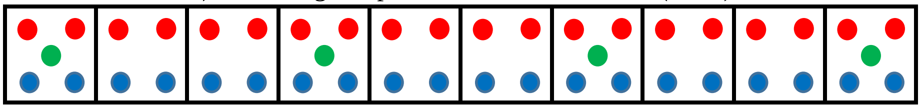
Fig. 1: Schematic of spacer fabrics with V and W patterns



a) Full Threading of Spacer Yarn (D-1)



b) Threading of Spacer Yarn in Even Dents (D-01)



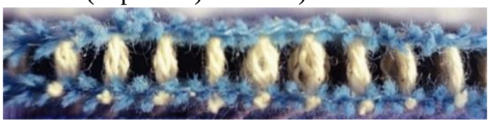
c) Threading of Spacer Yarn Once in a Three Dent Repeat (D-001)

Fig. 2: *Different threading of spacer yarn in weaving reed (Red dots: warp yarns for upper layer, Blue dots: warp yarns for lower layer, Green dots: spacer yarns)*

In Figure 3, the images of the longitudinal and transverse cross sections of the spacer woven fabrics are presented.

a) Cross section of Spacer fabrics (V pattern)

b) Cross section of Spacer fabrics (W pattern)



c) Transverse cross section

Fig.3: *Longitudinal and transverse cross section of spacer fabrics with V and W pattern*

Moreover, the constructional and physical characteristics of the woven spacer fabrics, are gathered in Table 1.

As it is clear in Table1, the warp and weft densities of the upper and lower layers of the woven spacer fabrics were constant and only the change in the pattern and density of spacer yarn, resulted in the variation of different samples' properties.

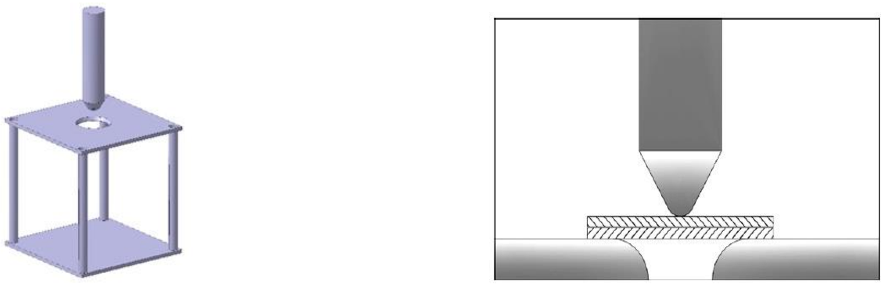
Table 1: *Specifications of the woven spacer fabrics*

Sample Code	Spacer yarn pattern	Type of threading in weaving reed	Warp density (cm^{-1})	Weft density (cm^{-1})	Fabric thickness (mm)	Areal weight (g/m^2)	Spacer yarn density (cm^{-2})
S1	V	D-001	9	10.5	10.08	978	15.6
S2	V	D-01	9	10.5	9.63	1021	26.0
S3	V	D-1	9	10.5	8.49	1283	52.1
S4	W	D-001	9	10.5	6.45	798	13.5
S5	W	D-01	9	10.5	8.63	964	22.5
S6	W	D-1	9	10.5	7.89	985	33.3

2.1 Testing Method

Measuring the bending resistance of the spacer fabrics have been performed based on the standard test method for stiffness of fabric by the circular bend procedure (ASTM D 4032). The circular bend procedure offers a load value related to fabric stiffness, simultaneously averaging stiffness in all directions. In this platform, the fabric is placed on a smooth plate ($200 \times 200\ mm^2$) with a 40 mm orifice on it and a plunger which is mounted concentric with the orifice, forced the fabric down through the orifice on the plate. The lap edge of the orifice should be at a 60° angle in order to decrease the stress concentration. The platform was placed on the Instron testing machine 5566 and the required force to pass the fabric through the orifice was recorded by the load cell. The platform and the placement position of the samples are shown in Figure 4.

The test was carried out, using $5 \times 5\ cm^2$ samples and the speed of the test was set on 100 $^{mm}/_{min}$. Maximum bending force (the peak force of the load-displacement curve) and bending energy (area under the curve) were reported as the results of the test.



(a) (b)

Fig.4: *(a) The platform in circular bend procedure and (b) the placement of the sample*

3. RESULT AND DISCUSSION

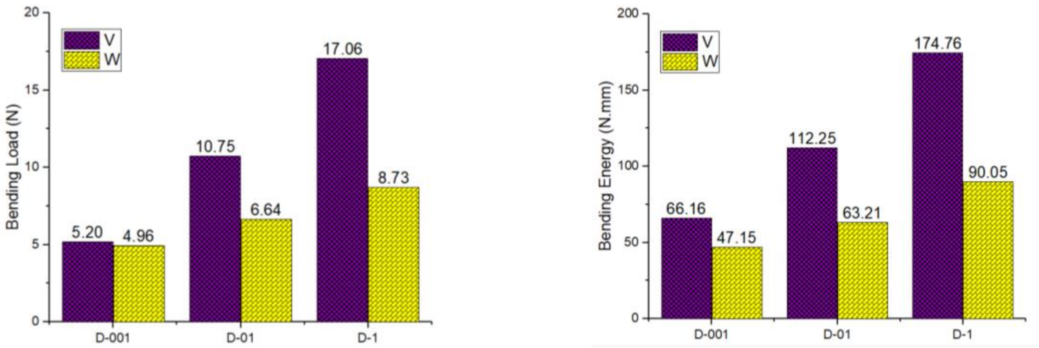
The average value of maximum bending force and bending energy of spacer woven fabrics with two different spacer yarn patterns and three different spacer yarn densities are reported in Table 2.

Table 2: The results of bending force and bending energy

Sample Code	Bending force (N)	Bending energy (N.mm)
S1	5.20	66.16
S2	10.75	112.25
S3	17.06	174.76
S4	4.96	47.15
S5	6.64	63.21
S6	8.73	90.05

The comparison of maximum bending force and bending energy between different spacer fabrics are shown Figure 5 (a) and (b), respectively. According to these graphs, the maximum bending load and bending energy in spacer fabrics with V pattern are higher than spacer fabrics with W pattern. Increasing the bending resistance is related to the difference in fabric structure. In spacer fabrics with V pattern, for any single warp and weft yarns, there is one vertical spacer yarn which connects the upper and lower layers, in the spacer fabric structure. So the number of spacer yarns per unit area increases and fabric's resistance to the applied bending load and bending energy rises.

The graphs of Figure 5 also revealed that by considering the constant spacer yarn pattern, bending resistance of spacer fabrics with D-001 threading pattern (threading of spacer yarn once in a three dent repeat) in weaving reed is less than spacer fabrics with D-01 (threading of spacer yarn in even dents) and D-1 threading patterns (full threading of spacer yarn), respectively. This phenomenon occurred because of difference in density of spacer yarn in the fabric structure. In spacer fabrics with D-001 threading pattern of spacer yarn, the density of spacer yarns in per unit area is less than two other kinds of threading. Therefore, bending resistance decreased in this kinds of spacer fabrics and their flexibility increased. On the other side, in case of spacer fabrics with D-1 threading pattern, the density of spacer yarns per unit area was much more than other spacer fabrics and this fact made the spacer fabric stiffer and less flexible.



(a) (b)

Fig.5: *Comparison of (a) bending load and (b) bending energy in woven spacer fabrics*

In order to investigate the effect of spacer yarn pattern (V and W pattern) and spacer yarn density (D-1, D-01 and D-001 threading patterns in the weaving reed) on maximum bending load and bending energy of woven spacer fabrics, statistical analysis of the results was performed, using the ANOVA test at the confidence level of 95%. The results of statistical analysis are shown in Table 3.

Table 3: Statistical analysis of variables on bending resistance

Bending parameter	P-Value		
	Spacer yarn pattern	Spacer yarn density	Spacer yarn pattern*spacer yarn density
Maximum bending load	0.000	0.000	0.000
Bending energy	0.000	0.000	0.000

According to Table 3, the effect of spacer yarn pattern, spacer yarn density and interaction between these two variables are significant on the maximum bending load and bending energy. This result confirms the trends of graphs in Figure 5.

4. CONCLUSION

Spacer fabric is a three-dimensional fabric consisting of two separate substrates, which are joined together or kept apart by spacer yarns and can be produced in weaving, warp knitting and weft knitting systems. In this study, in the first step, woven spacer fabrics were produced with different spacer yarn patterns and densities, using a shuttle loom. Polyester yarn was chosen as the warp and weft of the fabrics, and cotton was selected as the spacer yarn. Considering two spacer yarn patterns and three different densities for spacer yarns (three kinds of threading in weaving reed), six different samples were produced. In the second step, bending resistance of woven spacer fabrics were analyzed based on the circular bend procedure. The maximum bending load and bending energy were recorded and the results were analyzed. According to the outcomes of the tests, it was observed that increasing the number of spacer yarns per unit area of the fabric makes the spacer fabric inflexible and higher load is required to bend the fabric. This trend was also observed in spacer fabrics with V pattern and full threading of spacer yarn in the fabric structure. Furthermore, statistical analysis revealed that the effects of spacer yarn pattern and density, on the bending resistance of spacer fabrics are significant.

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