The Effect of Heat-Setting Conditions on the Performance Characteristics of Warp Knitted Spacer Fabrics

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ABSTRACT
Spacer fabrics can be produced by using weaving or nonwoven techniques besides warp and weft knitting processes. Warp knitted spacer fabrics are produced by using polyester multifilament and monofilament yarns for surface layers and spacer yarn, respectively. After knitting process, surface layers of these fabrics are in the closed form. Then these fabrics are subjected to a heat-setting treatment in order to increase their structural stability and to achieve an open form with holes. In this study, it is aimed to investigate the effect of heat-setting conditions on the performance characteristics of the warp knitted spacer fabrics. Mass per unit area, thickness, air permeability, compressibility, dimensional stability and compression set properties were measured and evaluated statistically in order to determine the effects of heat-setting conditions such as temperature, duration of heat-setting and stretching (the tension applied to the samples during heat-setting) on the performance characteristics. The results revealed that, heat-setting process has significant effect on all measured performance characteristics of the samples. After heat-setting process, air permeability and compressibility values increases while mass per unit area and compression set values decreases.

INTRODUCTION
Spacer fabrics are three dimensional textile structures consisted of two parallel knitted fabrics connected by a yarn layer called as spacer yarn. The spacer yarn plays an important role of fabric's special characteristics. With these special properties like compression and impact resistance, high breathability, high elastic recovery characteristic, spacer fabrics offer a lot of possibilities in various application areas such as medical textiles, automotive textiles, geotextiles, protective textiles, sportswear and composites. It is possible to produce these fabrics by weaving or nonwoven techniques besides warp and weft knitting processes. Knitting technology especially warp knitting technique is the most commonly known and applied technology for the production of spacer fabrics [1].

In the production of warp knitted spacer fabrics, especially polyester multifilament and monofilament yarns are used as surface layers and spacer yarn, respectively. These fabrics are taken from the knitting machine in the form of closed structures. After knitting process, the warp knitted spacer fabrics are normally subjected to a heat-setting treatment in order to increase the structural stability and to achieve a determined open form. It is necessary to point out that heat-setting of a spacer fabric is not easy to be processed because it is difficult to firmly catch the two selvages of the spacer fabric on a conventional heat-setting machine. In order to solve this problem, the selvages of both sides of spacer fabrics were knitted without spacer yarns. Ye et al. mentioned that to extend these fabrics to the desired width during heat-setting process was difficult, because of longer underlaps of the spacer yarns or higher thickness or weight of spacer fabrics [2].

Fabrics produced from synthetic fibres or from blends containing such fibres are subjected to a range of different heat treatments during the various stages of their production. Heat-setting is the most important one, since it gives the product the desired characteristics to make it suitable for further processing and use by the consumer [3]. Karmakar explained heat-setting as a heat treatment by which shape retention, crease resistance, resilience and elasticity are imparted to the fibres. It also brings changes in strength, stretchability, softness, dyeability and sometimes on the colour of the material [4]. According to Gacén et.al., heat-setting improves the properties of the textile substrate (improves shrinkage resistance, removes any creases, guarantees level dyeing and improves the fabric handle) [3]. Militký states in his study the purpose of the heat-setting process supported by Mukhopadhyay and Gacén et al. as stabilization of fibre dimensions, relaxation of internal stresses in the fibre and creation or stabilization of the crystalline structure [3,5,6]. The heat-setting process, which assists in improving the morphology of the fibre, is determined by the temperature, duration of heat-setting, the tension applied to the substrates during heat-setting and the medium of heat-setting (air, solvents or water) [7]. Even a slightest variation in heat-setting conditions, namely temperature, time and tension influence the setting effect on the mechanical behaviour of fabrics, regardless of the system used. Basically, heat-setting involves the interaction between time and temperature, the influence of temperature being more important than that of time. The tension at which heat-setting is applied is also an important variable of this process [3].The structural and morphological changes due to heat-setting are presented in the review by Gupta [8].

Various researchers proposed the heat-setting conditions of polyester fabrics with different values. According to Karmakar, polyester goods are pre-set with hot air on pin stenters for 20-40 sec at 180-210°C according to the type, density and weight of the material, with minimum tension on the goods to control the dry heat stability less than the accepted 1% shrinkage [4]. Gacén et al. mentioned that, heat-setting of polyester (PET) fabrics is usually applied at temperatures between 160 and 220°C, and times within the range of 30-120 seconds [3]. Idumah and Nwachukwu stated that, for PET, heat-setting occurs at temperatures of 130-140°C in steam or 190-220°C in dry air in the presence of some tension and since Tg of PET is approximately 80°C, heat-setting of PET above its Tg would allow the polymer structure to attain dimensional stability [7]. The general expectations to determine the heat-setting conditions are that polyester fabrics are effectively dimensionally stable if it is set at a temperature of 30-40°C higher than the temperature to which the fibre is subjected to expose during subsequent processes so as to ensure the fabric attains dimensional stability [4, 7, 8].

The effect of different setting treatment (heat-setting, presetting, vacuum steaming process) on the physical, mechanical and dyeability properties of different yarn types were examined by various researchers [9-15]. Avinç et al. studied a mathematical model to compare the handle of polylactic acid (PLA) and polyethylene terephthalate (PET) fabrics throughout finishing steps. They measured low stress tensile, shear, bending, compression and surface properties by using the KES-FB. The results revealed that the mechanical and surface properties as well as handle of PLA and PET fabrics change significantly after different finishing stages. The difference between handle of PLA and PET fabrics has been significantly reduced after dyeing, drying, heat-setting and softening processes [16]. Jiang et al. investigated the process of warp knitting mesh for hernia repair and also its mechanical properties. They tried various heat-setting conditions and they found that the pushing strength is up to 540N after heat-setting, and 10% higher than the fabric before heat-setting. The widthwise shrinkage in 100°C for 60 minutes is down to 1.5% from 6% before heat-setting. At the same time, the lengthwise shrinkage is decreased from 4% before heat-setting to 0.65%. In addition, other advantages are obtained from the heat-setting, improving in the handle and increasing in the softness of the fabric [17]. Idumah and Nwachukwu studied the effect of time of heat-setting and wet processes on the tensile properties (fabric extension, linearity of load extension, tensile energy and tensile resilience) of PLA and PET fabrics using the KES-FB [7]. Yang and Kan examined the effect of heat-setting parameters (treatment time, treatment temperature, and tension) on shrinkage after dyeing and colour yield of PLA knitted fabric. The results revealed that lower shrinkage and higher colour yield can be achieved when: heat-setting time=60 s; heat-setting temperature=130°C; and tension=0%. After that, the PLA knitted fabric was treated under the optimum heat-setting condition and was dyed with 1% depth disperse dye, which produced a better dyeing result. However, the handle of the heat set PLA knitted fabric became stiffer and more resistant to shearing movement and had worse drape and bending recovery ability, while the appearance became fluffier and rougher [18]. Borhani et al. investigated the influence of some parameters such as the kind of spacer threads and also heat-setting under drawing on moisture transport properties of spacer fabrics. They found that, heat-setting under drawing affects the fabric dimensional properties and heat-setting under drawing of spacer fabrics increases the porosity and air permeability of sample while decreases the thickness and mass per unit area of sample. The heat-set sample with higher porosity and air permeability has higher moisture transfer [19].

In this study, it is aimed to investigate the effect of heat-setting conditions on the performance characteristics of the warp knitted spacer fabrics. Mass per unit area, thickness, air permeability, compressibility, dimensional stability and compression set properties were measured and evaluated statistically in order to determine the effects of heat-setting conditions such as temperature, duration of heat-setting and stretching (the tension applied to the samples during heat-setting) on the performance characteristics.

EXPERIMENTAL

Fabric Production

Spacer fabrics were knitted on a Karl Mayer RD 6 double-needle bar raschel machine equipped with six yarn guide bars (GB). While a 150D/48x4 polyester PTY and 300D/72x3 polyester PTY multifilaments were used to create the top outer and bottom outer layers. A polyester monofilament of 0.243 mm in diameter was used as spacer yarn to connect two outer layers. Yarn and machine details are listed in *Table I*. The distance between the needle bars of machine was set at 12.5 and 15 mm to produce the samples in two thicknesses. Surface and cross-sectional views of a fabric before and after heat-setting process are given in *Figure 1*.

TABLE I. Yarn and machine details.

Layers	Guide bars	Chain notation	Threading	Yarn
Top layer	GB1	2-2 / 2-2 / 0-0 / 0-0 / 2-2 / 2-2 / 0-0 / 0-0 / 2-2 / 2-2 / 1-1 / 1-1 / 3-3 / 3-3 / 1-1 / 1-1 / 3-3 / 3-3 / 1-1 / 1-1 //	Half	PES PTY 150D/48x4
	GB2	0-1 / 1-1 / 1-0 / 0-0 //	Full	PES PTY 300D/72x3
Spacer yarn	GB3	0-1 / 0-1 / 1-0 / 1-0 //	Half	0.243 mm polyester monofilament
	GB4	0-1 / 0-1 / 1-0 / 1-0 //	Half	0.243 mm polyester monofilament
Bottom layer	GB5	0-0 / 0-1 / 1-1 / 1-0 //	Full	PES PTY 300D/72x3
	GB6	1-1 / 2-2 / 2-2 / 0-0 / 0-0 / 2-2 / 2-2 / 0-0 / 0-0 / 2-2 / 2-2 / 1-1 / 1-1 / 3-3 / 3-3 / 1-1 / 1-1 / 3-3 / 3-3 / 1-1 //	Half	PES PTY 150D/48x4

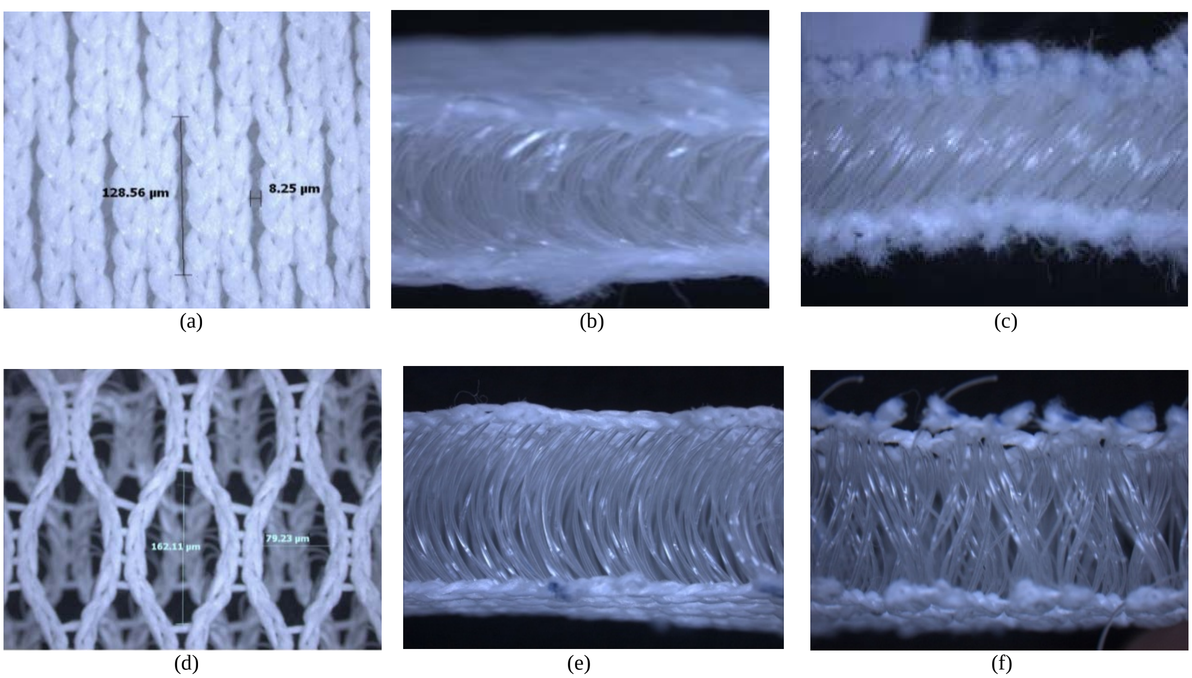

FIGURE 1.(a, d) Surface views of a sample before and after heat-setting process, (b, e) cross-section views along the course direction before and after heat-setting process, (c, f) cross-section view along the wale direction of a sample before and after heat-setting process.

Brückner (Vn-Sfp-24/6-Q99) heat-setting machine was used in order to increase the structural stability and to achieve a determined final width (stretching). The samples were horizontally (course-wise) pinned on the sliding aluminium frame pins and heat set at the temperatures of 150°C and 180°C for time durations of 1.8 and 3min. The tension applied to the samples during heat-setting was arranged so that the final width of the samples will be 110 and 160 cm while the width of unset fabrics which refers to the fabric width after knitting process was 60 cm. After heat-setting, the fabric samples were allowed to cool down at room temperature for 24 hours. Details of heat-setting process were given in *Table II*.

The performance characteristics of heat-set samples and unset samples referred to fabric taken from the knitting machine were compared and analysed statistically.

TABLE II. Details of heat-setting process.

Nr.	Distance between the needle bars (mm)	Duration of heat-setting (min)	Temperature of heat-setting (^{0}C)	Stretching (cm)
1	12.5	-	-	60
2	12.5	3	180	110
3	12.5	1.8	180	110
4	12.5	1.8	180	160
5	12.5	1.8	150	110
6	15	-	-	60
7	15	3	150	160
8	15	3	150	110
9	15	3	180	160
10	15	1.8	150	160

Fabric Tests

Mass per unit area values were measured according to the TS EN 12127 standard.

Air permeability is the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material. Air permeability values were obtained by using Textest FX 3300 instrument according to TS 391 EN ISO 9237. Its principle depends in the measurement of air flow passing through the fabric at certain pressure gradient Δp. The results of the measurements are averages from the values of 10 readings.

Compression stress or compressibility can be defined as a decrease of initial thickness that occurs with an appropriate increase of compressive force. Initial thickness is considered as the thickness without applied force on the fabric surface [20]. Compressibility tests were carried out by Zwick Z010 Instrument based on the ISO 3386 standard. The instrument is composed of a rectangular presser foot with a contact area of 40x40 cm^2, which moves vertically at a speed of 100 mm/min. 2.5 kN was applied to the samples and the set compression rate is 40%. The results are averages of 3 readings in kPa.

The dimensional stability of a fabric determines whether a fabric has the potential to retain its original shape and remain stable, indicating it will not bubble or sag over time, when applied over a substrate, and its suitability for a specified use. Dimensional stability was tested according to the DIN 53377 standard. The samples are cut into square form of 10 x10 cm and are placed in an oven maintained at 90°C for 1h. The dimensional stability value was calculated according to the Eq. (1):

$$Dimensional\ \ stability\ \ (\%) = \frac{(l_O - l_F)}{l_O} x100 \qquad (1)$$

where l_o: The original dimensions of the specimen
l_F: The dimensions of the specimen after treatment

The compression set is the difference between the initial thickness and the final thickness of a test piece of the material after compression for a given time at a given temperature and after a given recovery time and is determined according to TS 2013 EN ISO 1856 standard. The samples (50x50x25 mm) are compressed at a rate of 75% and are placed in an oven maintained at 70°C for 22h. The compression set value was calculated according to the Eq. (2):

$$Compression\ \ set\ \ (\%) = \frac{(d_O - d_r)}{d_O} x100 \qquad (2)$$

where d_o: The original thickness of the specimen
d_r: The thickness value of the specimen waited for ½ h after experiment

As statistical evaluation ANOVA and Duncan multiple comparison tests were applied (p=0.05).

RESULTS AND ANALYSIS

The performance characteristics of the samples are given in *Table III*. The statistical analysis of the samples' characteristics (Mass per unit area, air permeability, compressibility) showed that, there is a significant difference (p=.000) between the samples for all groups (*Table IV*). In *Table III*, the mean values are marked with the letters 'a', 'b' and 'c' ('a' shows the lowest value and 'c' shows the highest value). Any levels marked by the same letter showed that they were not significantly different.

TABLE III. Performance characteristics of the samples.

Distance between the needle beds (mm)	Heat-setting conditions		Mass per unit area (g/m^2)	SD*	Thickness (mm)	SD*	Air Perm. (lt/m2s)	SD*	Compressibility (kPa)	SD*	Dim. stability %	Comp. set (%)
12.5	Duration (min)	Unset	1409.86(b)	14.26	11.43	0.077	1462(a)	82.92	4.31(a)	0.276	-1	39.73
		1.8	711.58(a)	14.46	11.14	0.045	5859(b)	115.45	16.45(b)	0.829	-3	25.52
		3	685.6(a)	28.42	11.16	0.049	5994(b)	127.76	17.49(b)	0.434	-3	28.51
15		Unset	1512.61(b)	28.47	12.35	0.045	1548(a)	54	0.15(a)	0.16	-2	37.3
		1.8	588.83(a)	6.35	12.76	0.073	6614(b)	106.79	8.74(b)	0.11	-3	33.4
		3	578.85(a)	8.72	12.74	0.037	6739(b)	219.88	9.95(b)	0.073	-3	35.98
12.5	Stretching (cm)	Unset	1409.86(c)	14.26	11.43	0.077	1462(a)	82.92	4.31(a)	0.276	-1	39.73
		110	711.58(b)	14.46	11.14	0.045	5859(b)	115.45	16.45(c)	0.829	-3	25.52
		160	515.26(a)	11.54	10.67	0.07	6807(c)	137.19	11.96(b)	0.166	-3	27.56
15		Unset	1512.61(c)	28.47	12.35	0.045	1548(a)	54	0.15(a)	0.16	-2	37.3
		110	731.04(b)	27.47	12.63	0.005	5644(b)	93.081	12.45(c)	0.475	-3	34.47
		160	578.85(a)	8.72	12.74	0.037	6739(c)	219.88	9.95(b)	0.073	-3	35.98
12.5	Temperature (^{0}C)	Unset	1409.86(b)	14.26	11.43	0.077	1462(a)	82.92	4.31(a)	0.276	-1	39.73
		150	721.89(a)	9.79	11.41	0.056	5587(b)	90.01	13.71(b)	0.136	-3	28.02
		180	711.58(a)	14.46	11.14	0.045	5859(c)	115.45	16.45(c)	0.829	-3	25.52
15		Unset	1512.61(b)	28.47	12.35	0.045	1548(a)	54	0.15(a)	0.16	-2	37.3
		150	578.85(a)	8.72	12.74	0.037	6739(b)	219.88	9.95(b)	0.073	-3	35.98
		180	553.28(a)	5.46	12.56	0.014	7009(c)	127.39	8.69(b)	0.139	-3	34.18

* **Standard Deviation**

TABLE IV. Statistical evaluation (p values) of the samples' characteristics.

	Duration (min)		**Stretching (cm)**		**Temperature (^{0}C)**	
	Unset – 1.8 – 3		**Unset – 110 – 160**		**Unset – 150 – 180**	
Distance between the needle bars (mm)	**12.5**	**15**	**12.5**	**15**	**12.5**	**15**
Mass per unit area	0	0	0	0	0	0
Air permeability	0	0	0	0	0	0
Compressibility	0	0	0	0	0	.054*

**This p value is not statistically significant for α=0.05*

The mean values of the mass per unit area showed that (*Table III*), unset fabrics have higher mass per unit area values and these values significantly decreased after heat-setting process. Statistical evaluation revealed that, heat-setting temperature and duration of heat-setting parameters didn't have any significant effect on this parameter, on the other hand the tension applied to the samples during heat-setting determined the surface structure and mass per unit area characteristics of the samples. The greater the tension, the higher is the final width of the samples. Consequently, the holes became on fabric surface and the amount of yarn per unit area is decreased.

It was found that the thicknesses of all fabrics were smaller than the distance set (12.5 and 15 mm) between the two needle bars of the machine. This is an expected situation because during knitting process, the spacer yarns were under tensioned states. After knitting, the spacer yarns tended to relax into bended forms. The bending of the spacer yarns resulted in the decreasing of the fabric thickness.

From *Figure 2*, it can be seen that, heavier unset fabrics have lower air permeability values than heat-set samples. Heat-setting process influences statistically the air permeability values of the samples significant, as shown in *Table IV*. While duration of heat-setting doesn't affect this parameter, heat-setting temperature and the tension or stretching creates differences between air permeability values of the samples. With the increase of the final width of the samples, the size of holes on fabric surface and air permeability of the samples increases also. The bigger pores on the surface layer after stretching lead to passing of the air easily through the fabric surfaces. Additionally, the air permeability values of the fabrics increase as the heat-setting temperature increases as well. It seems possible that these results are due to decrease of mass per unit area and thickness. As the fabrics get lighter and thinner, the amount of air passed through the fabric increases.

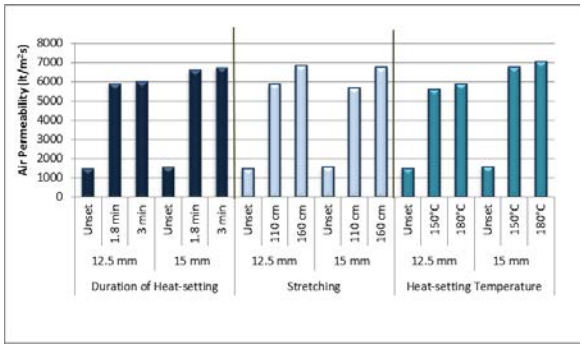

FIGURE 2. Air permeability values of the samples.

Compressibility characteristic of fabrics, along with the bending, tensile, shear, and surface characteristics are closely related to fabric handle, drape, and sewability properties. A fabric that compresses easily is likely to be judged as soft, possessing a low compression modulus or high compression [20]. The force necessary to compress a fabric has to overcome the internal stresses of the fibres and the inter-fibre frictional force [21]. According to *Figure 3*, the lowest compressibility values were obtained from unset fabrics. Also the results indicated that, the compressibility characteristics decreased as the thickness values increased. There is statistically significant difference between the unset and heat-set samples, as illustrated in *Table IV*. The parameters of heat-setting temperature and stretching have statistically effect on this parameter, whereas it has not been affected by the duration of heat-setting. With the increase of the final width of the samples, the compressibility behaviours decreased. This situation can be explained by higher mass per unit area values of the fabrics stretched to 110 cm. When comparing the effect of heat-setting temperature on this parameter, as the temperature increased, the compressibility values increased for the fabrics whose distance between the needle beds arranged at 12.5 mm. Statistical analysis showed that (*Table IV*) there isn't any significant difference for the fabrics their thicknesses arranged at 15 mm.

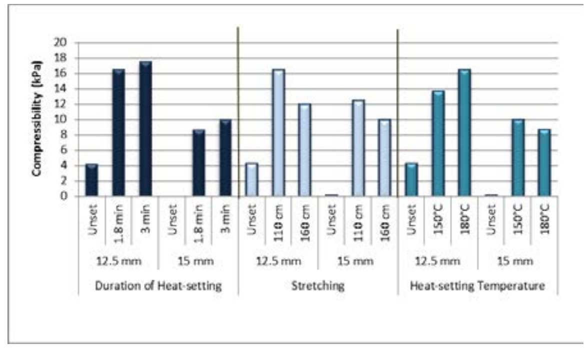

FIGURE 3.Compressibility values of the samples.

The dimensional stability characteristics of the fabrics were measured in both directions: wale-wise and course-wise. *Figure 4* illustrated the dimensional stability values in course-wise. According to DIN 53 377, the acceptable limit value of dimensional stability for both directions is ± 3%. The results indicated that, 3% shrinkage occurred in course direction after heat-setting, whereas there was no dimensional change in wale direction for all fabrics. Unset fabrics had lower dimensional change than heat-set fabrics. It could be seen from *Figure 4* and *Table III*; heat-setting conditions didn't have any effect on the dimensional stability attributes of the samples.

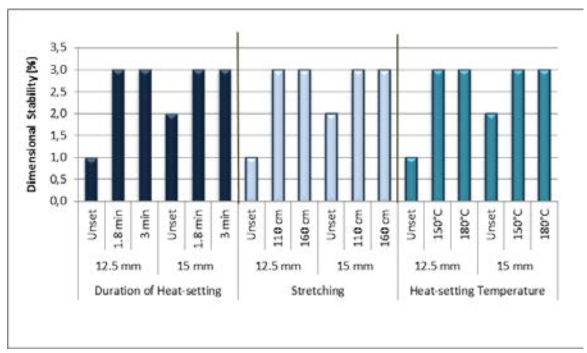

FIGURE 4.Dimensional stability values of the samples.

Compression set value known as aging test is one of the important factors determining the durability and lifetime of spacer fabrics. There is an inverse relationship between the durability and compression set characteristic of the fabrics. The higher the compression set, the lower is the durability of the fabrics. It can be seen from *Figure5* that, thinner fabrics have lower compression set values, especially after heat-setting process. Unset fabrics with higher compression set values offer a shorter lifetime of the fabrics. Heat-setting process has a significant effect for decreasing the compression set characteristic and consequently increasing the durability of the samples. Additionally, the compression set values of the samples increase as the parameters of duration of heat-setting and the stretching increase, whereas the increase of the heat-setting temperature leads to decrease in compression set values of the samples. With the increase in the duration of heat-setting, the fabrics are exposed to longer periods of heat which can reduce the durability of the materials. Additionally when the tension applied to the samples during heat-setting increases, the compression set values of the fabrics increase as well due to the decrease of fibre content per unit area. The effect of the heat-setting temperature on the compression set characteristic can be explained with the increase of crystalline structures in the yarn.

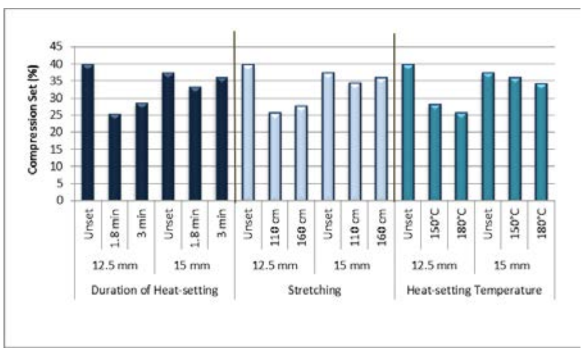

FIGURE 5. Compression set values of the samples.

CONCLUSION

This study performs an investigation of the effect of heat-setting conditions on the performance characteristics of the warp knitted spacer fabrics. Mass per unit area, thickness, air permeability, compressibility, dimensional stability and compression set properties were compared with the unset fabrics and evaluated statistically in order to determine the effects of heat-setting conditions such as temperature (150°C vs. 180°C), duration of heat-setting (1.8 vs. 3 min) and stretching (110 vs. 160 cm) (the tension applied to the samples during heat-setting) on the performance characteristics. The results have clearly demonstrated that:

- After heat-setting process, air permeability and compressibility values increased while mass per unit area and compression set values decreased.
- Among the heat-setting conditions examined in this study, only the stretching parameter affected the mass per unit area values significantly. The higher the stretching, the lower is the mass per unit area values of the fabrics.
- Heat-setting temperature and the tension or stretching parameters create differences between air permeability and compressibility values of the samples while these parameters are not affected by the duration of heat-setting. With the increase of the final width of the samples and the heat-setting temperature, the air permeability of the samples increased also. On the other hand the compressibility property has an inverse relationship with the final width of the fabrics.
- 3% shrinkage occurred in course-wise for all samples after the heat-setting process.
- The most important parameter, affected the compression set and compressibility characteristics is thickness of the samples. Thinner fabrics have lower compression set values, resulting higher durability and long lifetime. Heat-setting process has a significant effect for decreasing the compression set characteristic and consequently increasing the durability of the samples. Additionally, the compression set values of the samples increase as the parameters of duration of heat-setting and the stretching increase, whereas the increase of the heat-setting temperature leads to decrease in compression set values of the samples.
- Due to the heat-setting process, spacer fabrics' characteristics like compressibility, compression set and breathability could be enhanced.

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