Analysis of the heat setting process

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Abstract. Heat setting is an expensive and energy elaborative textile process. Heat setting is necessary to guarantee size accuracy and dimensional stability for textile materials. Depending on the material different heat setting methods such as saturated steam or hot air are used for the fixation. The research aim is to define the influence of heat setting on mechanical characteristics and to analyse the correlation of heat setting parameters for polyester. With the help of a “one factor at a time” experimental design heat setting parameters are varied. Mechanical characteristics and the material quality of heat set and not heat set material are evaluated to analyse the heat setting influence. In the described experimental design up to a temperature of 195 °C and a dwell time of 30 seconds the material shrinkage of polyester is increasing with increasing temperature and dwell time. Shrinkage in wales direction is higher than in course direction. The tensile strength in course direction stays constant whereas the tensile strength in wales direction can be increased by heat setting.

1. Introduction
The Institut für Textiltechnik (ITA) der RWTH Aachen University is researching in the area of textile mechanical engineering, in textile simulation [1] as well as in quality control, automation [2] and energy efficiency [3]. The research fields in the area of knitting are improvements in pattern and process engineering [4]. ITA started researching on heat setting since July 2015 to analyse the process correlations. The heat setting process can be adjusted in a more efficient, innovative and user-friendly way based on fundamental process knowledge.

Heat setting is a thermal and mechanical process to guarantee size accuracy and dimensional stability for textile materials. Textile construction causes constraints on the textile. Constraints occur due to the arrangement of dipole links and hydrogen bonds, as well as crystallisation and chain stiffness. During the heat setting process these inner constraints are rearranged. Thus the dimension of the textile is changing. Depending on the material different heat setting methods such as saturated steam or hot air are used for the fixation. The standard method for the heat setting of synthetic material is the continuously used stenter frame. The stenter frame heat sets by using hot air. Important process parameters are temperature, dwell time, width and overfeed. For natural fibres relaxation dryers, crimping and steaming units are used [5-9].

Heat setting is an expensive and energy elaborative textile process. The correlation of heat setting parameters is analysed to determine the potential for process optimization. Models for optimum dimensional stability have been obtained for knitted cotton/elastane fabrics [10]. In this work further textile characteristics of polyester knitted samples are analysed with a “one factor at a time” experimental design. It is analysed how the textile characteristics (average weight, mesh density,
thickness and tensile strength) change depending on the heat setting parameters. The relationship between temperature and time is always depending on the polymer and the textile characteristics such as fabric weight and construction [5].

2. Experimental setup
For the experimental design circular knitted polyester tube samples are used. The tubes are knitted on the machine BSM 3.0 from Beck GmbH, Albstadt. The machine has a diameter of 30” and a gauge of E24. The used polyester yarns have a specification of 167/ 48-1 CS. The tube samples have a size of 120 cm width and 60 cm height and have a single jersey structure. The average weight of the tube samples is 85 g/m² and the thickness is 0.5 mm. The mesh density in course direction is 12/cm and the mesh density in wales direction is 11/cm. The maximum tensile strength in course direction is 145 N and 214 N in wales direction.

A “one factor at a time” experimental design is carried out on the fixation press CC600 from Herbert Kannegiesser GmbH, Vlotho. The fixation press is working discontinuously. The polyester tube samples are placed on a belt. The samples are transported and heat set in course direction. The material is heated with heating panels from above and below. In addition the polyester samples can be pressed with the help of two pressure rolls. The pressure rolls are located behind the heating zone. After that the samples are falling onto a second belt, where the samples cool down. In the “one factor at a time” experimental design temperature and dwell time are varied on four levels, pressure is varied on two levels. The definition of the different levels is shown in Table 1.

Table 1. Level for heat setting parameters.

| Level | Temperature [°C] | Dwell time [sec] | Speed [m/min] | Pressure [bar] |
|-------|------------------|------------------|---------------|---------------|
| 1     | 180              | 6.5              | 5.5           | 0             |
| 2     | 185              | 9                | 4             | 1             |
| 3     | 190              | 14.4             | 2.5           | -             |
| 4     | 195              | 36               | 1             | -             |

Textile characteristics are analyzed in order to see how heat setting parameters are correlating. The influence of heat setting on textile characteristics has to be identified to evaluate the correlation of heat setting parameters. Shrinkage is the most important quality factor for heat setting. Shrinkage is the dimensional change of textile occurring during heat setting. Analyzed textile characteristics are the average weight (DIN EN 12127), the mesh density (DIN EN 14971), and the thickness (DIN EN ISO 5048) to define the shrinkage. In addition the behavior of the tensile strength (DIN EN ISO 13834-2) is measured.

3. Results
During the knitting and the heat setting process many disturbance values occur. Disturbance values are for example variation in the knitting process, an imprecise temperature regulation in the fixation press, no possibility of material guidance during the heat setting process and thus occurring rolling of the edges. Due to these disturbance values high variation can be seen in the results and no assured statements can be made. Nevertheless tendencies of material behavior can be indicated.

The average weight is determined according to DIN EN 12127. The development of the average weight for the single jersey samples are shown in Figure 1. Five measurements are performed for each setting. The average weight of the reference material is 85 g/m². The average weight for heat set material is higher than for the reference material. Measurements are fluctuating around 87 g/m². During heat setting the material shrinks. Shrinkage means that the density of yarn increases. Thus the average weight is increasing as well. The average weight is increasing with temperature and time. The highest average weight of 90 g/m² is obtained at 195 °C and a dwell time of 36 seconds. Regarding additional pressure no assured influence on the average weight can be seen.
The thickness of the samples is determined according to DIN EN ISO 5048. Five measurements are performed for each setting. Figure 2 shows a decreasing thickness with increasing temperature. The same effect can be seen with increasing dwell time. Assuming that yarn is shrinking evenly, the size of the textile has to be reduced in all dimensions. Regarding the influence of pressure on the thickness no assured statements can be made. The standard deviation of the samples heat set with additional pressure is high. The course of the different curves indicates that pressure does not have an influence on the thickness of the material. A possible reason is the short time the material is exposed to the pressure rolls.
The mesh density is determined according to DIN EN 14971. Five measurements are performed for each setting. Figure 3 shows the mesh density in dependence of the temperature. The mesh density in course direction is constant (12/cm) for all temperature and dwell time levels. An influence of pressure is not visible. The mesh density in wales direction is increasing with increasing temperature and dwell time. The highest increase from 10.6/cm to 12/cm occurs at the highest temperature (195 °C) and the highest dwell time (36 sec) level. This means that the tested structures show a higher shrinkage in wales direction than in course direction. This can be explained by the unsymmetrical knitted mesh structure. The mesh structure is shown in Figure 4. The distance between two crossing points in wales direction is larger than in course direction thus the material in wales direction has more space to relax and shrink than the material in course direction. Another factor that needs to be considered is the reference mesh density. The mesh density in course direction is higher than in wales direction. On the one hand this means that there is more material having the possibility to shrink. On the other hand there is the possibility that the density is already so dense, that there is no possibility of further shrinkage due to a lack of space.

**Figure 2.** Thickness depending on temperature for different dwell times.
Figure 3. Mesh density depending on temperature for different dwell times.

Figure 4. Knitted structure

Tensile strength is determined according to DIN EN ISO 13834-2. The results for the single jersey samples are shown in Figure 5. Five measurements are performed for each setting. For the single jersey samples anisotropic behavior of the tensile strength can be identified. The material behavior in course direction is different than in wales direction.
In course direction heat setting has a marginal influence on the tensile strength. The reference sample has a tensile strength of 145 N. The highest value reached for a heat set sample is 159 N, which is equivalent to a strength increase of about 10 %. The tensile strength is approximated to be constant for all heat setting level. An influence of pressure cannot be indicated. The tensile strength in wales direction is increasing with increasing temperature and dwell time compared to the reference sample. The maximum value for tensile strength in wales direction is 317 N, which is an increase of 48 % to the not heat set reference sample (214 N).

![Tensile strength depending on temperature for different dwell times.](image)

**Figure 5.** Tensile strength depending on temperature for different dwell times.

The tensile strength in course direction (145 N) is low compared to the tensile strength in wales direction (317 N). This result is equivalent to the results of the mesh density. With increasing mesh density in wales direction, there is more material taking up the forces of the tensile load. The tensile force can be distributed evenly. Furthermore filaments are taking the most loads in filament direction. Most parts of the filaments are oriented in wales direction thus more forces can be taken up in this direction (see Figure 4). Another cause for the increase of the tensile strength in wales direction is the transformation from amorphous into crystalline structures, which have a positive effect on the tensile strength. Higher temperatures and longer dwell times lead to a higher degree of crystallinity. Crystal growth in wales direction is encouraged by the knitted structure. The high amount of parallel yarn in wales direction develops more crystal structures than the short parallel yarn parts in course direction. The maximum tensile strength in wales direction grows [5].
Figure 6. Correlation of dwell time and temperature for different characteristics.

A correlation between dwell time and temperature for each textile characteristic is shown in Figure 6. For the average weight linear regression for the dwell times of 6.5 sec and 9 sec and for the thickness for the dwell times of 9 sec and 36 sec can be approximated. For the mesh density (wales direction) the dwell times of 14.4 sec and 36 sec and for the tensile strength (wales direction) the dwell times of 9 sec and 14.4 sec can be approximated with linear regression. The linear regression models show that one desired textile characteristic (e.g. average weight) can be reached with different parameter combinations. Not all correlations can be approximated in linear regression models. More data have to be collected in order to define an appropriated model to describe the correlation between...
temperature and dwell time for each textile characteristic. The high standard deviations (see Figure 1-Figure 6) put the linear regression model into perspective.

4. Summary and Conclusion
In this paper the influence of heat setting on the textile characteristics of a polyester single jersey structure are analysed. The shrinkage is slightly increasing with increasing temperature (max. 195 °C) and increasing dwell time (max. 36 sec.). The mesh density and tensile strength in wales direction are increasing, whereas in course direction the increase is marginal and assumed to be constant. Pressure does not show any influence on the textile characteristics. To reach a desired textile characteristic different combinations of temperature and dwell time are possible.

For modelling the heat setting process further data has to be collected to improve and verify obtained models. For the engineering of technical textiles further analyses have to be done regarding the different behaviour of shrinkage and tensile strength in course direction and wales direction for different mesh densities. That way it can be analysed whether there is a mesh density limit for knitted structures. Another possibility is to analyse the crystalline structures to obtain more information about the increase of tensile strength. Furthermore results have to be transferred to the classical stenter frame heat setting and include washing tests to define the stable state.

Economic effects of the different heat setting parameters have to be analysed. Thus a data base with included economic effects can determine heat setting parameters for special textile characteristics. The data base can serve for the optimization of the heat setting process. The correlation of economic factors as well as quality factors can lead to conserving resources by energy reduction.

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