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Influence of heat treatment on mechanical and sorptional properties of viscose-based nonwovens

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The influence of heat treatment on sorptional and mechanical properties of viscose: polypropylene (90:10) blend nonwoven fleeces has been studied. It is observed that the heat treatment improves mechanical properties (rupture resistance and tensile strength) and slightly decreases sorptional properties (degree of water retention and rate of water absorption) of cloths. The optimum heat-treatment temperature needed to obtain the highest breaking force and water absorption of nonwovens is found to be 165-170°C. Microstructural analysis proves that the nonwovens have the point bonding form of web when heat treatment is performed at optimum temperature.

Keywords: Mechanical properties, Nonwoven fleece, Polypropylene, Sorption properties, Viscose
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1 Introduction

The thermally-bonded nonwovens show a continuous expansion and renewal in the past five years due to their diversity, multiple and growing application possibilities, and versatile, flexible and permanently evolving manufacturing process[1,2]. In spite of the progress in spun-bonded materials, the staple-based technologies have advantages over spun-bonded materials in several aspects. By using staple-based technologies, it is possible to obtain bulky products (multi-layers and composite structures for acquisition and distribution applications, filtration media, medical wound dressings, etc.) and specifically designed fabrics where fibre blends are needed as well as to obtain the diversity of properties which can be designed with fibres. All these, combined with fast and efficient change from one product to other, and the low investment cost of thermally-bonded materials gave a leading role to the materials produced by staple-based technology[1].

Viscose, the oldest commercial man-made fibre, was a predominant fibre used in the nonwovens industry until mid 80s (refs 3-5). The market share of viscose nonwovens initially decreased, but has gradually picked up since 1990 (refs 6, 7). The main usage of viscose in nonwovens is for medical, surgical and sanitary products, and wipes[3,4,7]. The wipes represent the largest nonwovens market for viscose[3,8,9].

Nonwoven textile materials based on viscose are used as cleaning cloth and dry wipes due to their cleanliness and absorptive properties[4]. These cloths are obtained either by chemical bonding of main layer or by heat treatment of viscose-thermoplastic fibre blends. During the heat treatment, the thermoplastic fibres melt connecting the fibres of the fleece into cloth with appropriate mechanical properties. The advantage of viscose-based nonwovens obtained by heat treatment is their almost complete biodegradability[3,8].

The present work was, therefore, aimed at finding out the correlation between structural characteristics of web and heat treatment conditions, especially considering the temperature as key parameter of synthesis. The effect of heat treatment on the mechanical and sorptional properties of viscose: polypropylene (90:10) fleeces has also been studied.

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2 Materials and Methods

Viscose fibres (90%) and polypropylene fibres (10%) were used to prepare fleece by cross-wise lying on web and then needling. All the mechanical operations were performed in facilities of "INTEX", Mladenovac, Serbia.

Different heating temperatures were used to obtain the most appropriate condition for cloth production. A "Heraus" oven with a controlled heating rate was used for heating. The temperature inside the oven was monitored using a HP 3497 Data Acquisition System. The maximum heating temperatures used were 150°C, 160°C, 170°C, 180°C and 190°C. The samples were heated at a heating rate of 50°C/min and kept at the maximum temperature for 3 min.

The fabric properties were evaluated as per the standard methods used earlier[10-15] and by the microscopic investigation of the microstructure. The studies were performed in both needling direction (↑) and perpendicular to the needling direction (→).

The measurement of breaking force (F_p) was performed according to JUS.F.S2.017 on a horizontal dynamometer (AVK, Hungary)[11]. For each set of experiments, five testing samples (50 mm × 200 mm) were cut out of the cloth in both directions (↑,→).

The wear resistance was measured according to JUS.F.S2.023 (ref. 12) using Branca Idealair (Model 65), Italy. For each set of experiments, five testing samples (50 mm × 500 mm) were used in both directions (↑,→). The area exposed to abrasion by grinding paper was taken as 25 cm^2. Each sample under the load performed recurrent translation motion having 35 abrasive cycles in a minute. The wear is defined as the number of abrasive cycles needed to cause the rupture of cloth.

The rupture resistance was measured according to JUS.F.S2.022 (ref. 13) using the metal ball (ϕ=20 mm) on the same dynamometer as used for breaking force measurements. Five testing samples (100 mm × 100 mm) were used for each set of experiments. The force (F_B) needed to obtain rupture was recorded as rupture resistance.

Water retention power was calculated according to DIN 53 814 (ref. 14) using four specimens for each sample cut out from the cloth in both directions (↑,→).

Rate of water absorption was estimated as a water level after 10, 30 and 60 s of water absorption by the studied cloths. These measurements were performed according to DIN 53 924 (ref. 15) in both directions (↑,→).

The structural analysis was performed using Ergaval Carl Zeiss-Jena microscope.

3 Results and Discussion

Fig. 1 shows the breaking force (F_p) of the nonwoven samples in both directions (↑,→). The breaking forces of the heat-treated samples were compared to those of the untreated ones. The experimental results were fitted by Gaussian fit. The samples that did not undergo heat treatment have breaking force smaller than that of the heat-treated nonwoven samples for both the directions. Due to the method used for web laying, there is a difference in tensile strength in both the directions. The cross-laid webs have a higher tensile strength in the cross direction than in the longitudinal direction[16]. Therefore, the breaking force in needling direction is expected to be approximately 3-3.5 times lower than that in the perpendicular to needling direction. Heat treatment undoubtedly increases breaking force in both the directions, but dependence of breaking force to maximum heat-treatment temperature is complex. By fitting experimental results with Gaussian fit, it is possible to establish the peak value as centre of Gaussian curve. Assuming that the peak value is obtained for the optimum heat-treatment temperature, the optimum heat-treatment temperature needed to obtain the highest breaking force is found to be 164.52±8.77°C for needling direction and 170.61±9.21°C for perpendicular to the needling direction.

The influence of heat treatment on rupture resistance is shown in Fig. 2. The force (F_B) needed to

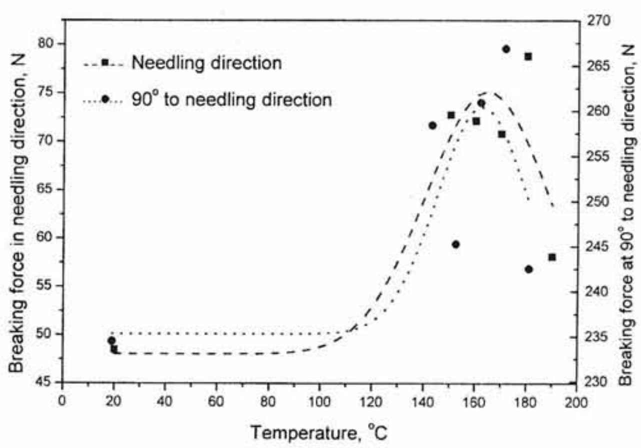


Fig. 1—Breaking force *vs* maximum heat-treatment temperature

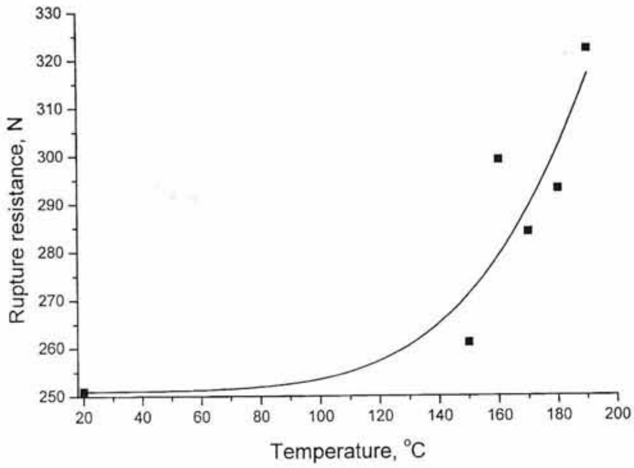


Fig. 2—Rupture resistance *vs* maximum heat-treatment temperature

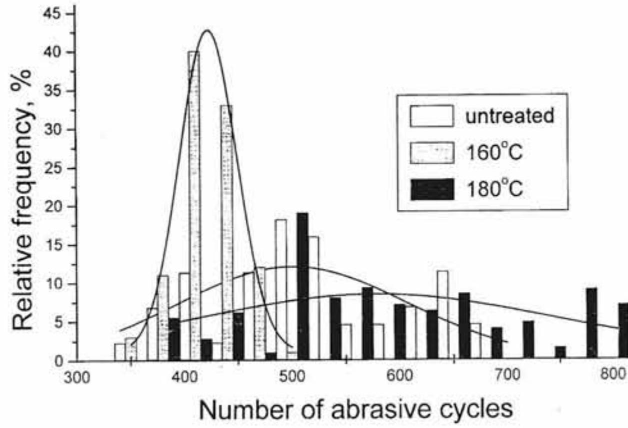


Fig. 3—Histograms of wear resistance of samples

obtain rupture increases exponentially with the increase in heat-treatment temperature in all investigated temperature intervals.

Fig. 3 shows the histograms of wear resistance values of untreated samples and the samples treated at 160°C and 180°C for perpendicular to needling direction. Very similar results were obtained for the samples in the needling direction. Neither the mean value of wear resistance nor the standard deviation of mean value show any regular pattern depending on heat treatment. Therefore, the regularity of wear resistance on heat-treatment temperature has not been obtained. Probably, other process parameters have more significance on wear resistance than heat-treatment temperature.

The mean values of degree of retention of water and the standard deviations of these values for both untreated and heat-treated samples are given in Fig. 4. Degree of retention of water (DRW) of all the samples is between 47.3% and 53.3%. Standard deviation of DRW for all the samples is 1.0-2.7%. The DRW is somewhat higher for untreated samples than that for all heat-treated samples. The decrease in the degree of water retention by heat treatment is almost insignificant.

The rates of water absorption after 10, 30 and 60s in both needling direction and perpendicular to needling direction are given in Figs 5 and 6 respectively. The rate of water absorption is lower in needling direction. The untreated samples have higher rates of water absorption than the samples that undergo heat-treatment, but at optimum heat-treatment temperature the rate of water absorption almost reaches the value of untreated samples.

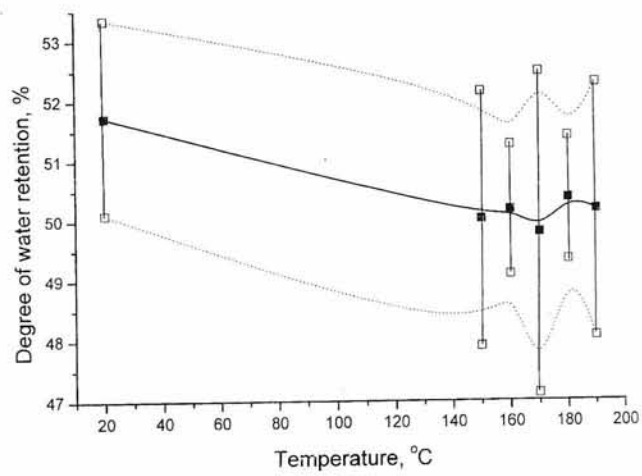


Fig. 4—The mean values and standard deviation of degree of retention of water *vs* maximum heat-treatment temperature

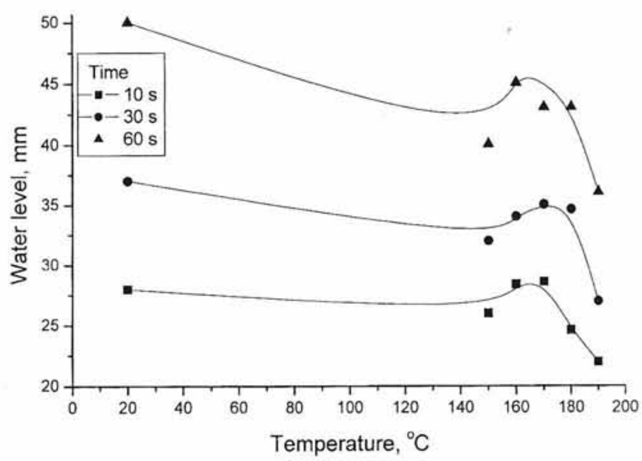


Fig. 5—Influence of heat treatment on rate of water absorption in needling direction

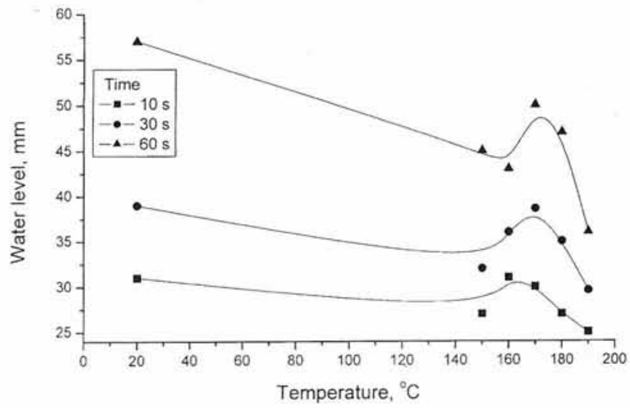


Fig. 6—Influence of heat treatment on rate of water absorption in perpendicular to needling direction

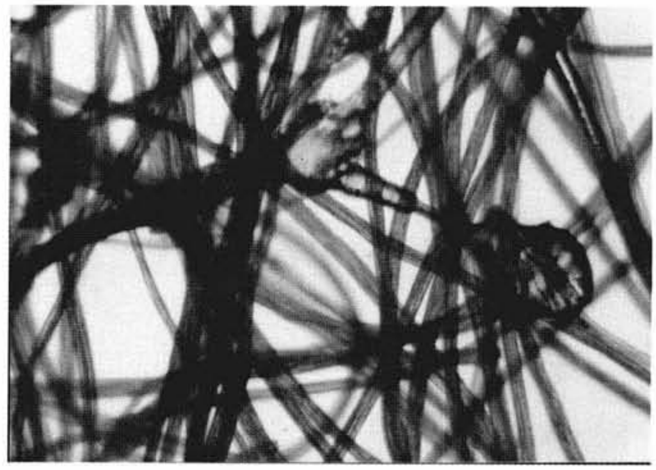
Table 1—Calculated optimum maximum heat-treatment temperatures for all the water absorption conditions

Needling direction	Absorption time s	Optimum temperature °C
↑	10	164.00 ± 0.72
↑	30	166.69 ± 2.18
↑	60	166.13± 2.01
→	10	164.25 ± 0.64
→	30	168.18 ± 0.78
→	60	166.83 ± 3.69

According to mathematical analysis, the optimum heat-treatment temperatures are given in Table 1. The best rate of water absorption in both the directions is obtained when heat treatment is performed at 166.83± 3.69°C.

By analyzing the microphotographs of all the samples, it was possible to explain the obtained properties. With the increase in temperature from 150°C to the optimum temperature, the softening of polypropylene fibres turns to complete melting. On melting, polypropylene becomes a bonding agent that forms bridges at the points of intersection of fibres within web. These bonds are responsible for improvement in mechanical properties of the cloth. Fig. 7 shows the microphotograph of sample heated at 170°C. This thermally-bonded nonwoven has the point bonding form.

The decrease in breaking force on temperatures higher than the optimum temperature can be explained by forming film-like bonding forms. These bonding forms are tiny and due to the changes in polypropylene fibres, caused by the elevated temperatures, occasionally poorly adhered and therefore do not play satisfactorily their bonding role.



100 μm

Fig. 7—Microphotograph of sample obtained at 170°C

On the other hand, the rupture resistance continuously increases with the increase in temperature. This type of behaviour can be explained by the increase in bonding areas, which appears to be more significant for rupture resistance.

4 Conclusions

4.1 The heat-treatment of viscose:polypropylene (90:10) nonwoven fleeces improves the mechanical properties, while slightly decreases sorptional properties.

4.2 No regularity in dependence of wear resistance on heat-treatment temperature has been observed.

4.3 Rupture resistance increases exponentially with the increase in heat-treatment temperature.

4.4 The decrease in degree of water retention by heat treatment is almost insignificant.

4.5 The optimum heat-treatment temperature needed to obtain the highest breaking force and water absorption at the same time is found to be 165-170°C, observed according to the performed mathematical analysis of experimental results.

4.6 Microstructural analysis proves that the nonwovens have the point bonding form of web when heat treatment is performed at optimum temperature. This shows the correlation between structural characteristics of web and heat treatment.

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