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Strength of fibres in low-density thermally bonded nonwovens: An experimental investigation

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Abstract. Mechanical properties of nonwovens related to damage such as failure stress and strain at that stress depend on deformation and damage characteristics of their constituent fibres. Damage of polypropylene-fibre commercial low-density thermally bonded nonwovens in tension was analysed with tensile tests on single fibres, extracted from nonwovens bonded at optimal manufacturing parameters and attached to individual bond points at both ends. The same tests were performed on raw polypropylene fibres that were used in manufacturing of the analysed nonwovens to study quantitatively the effect of manufacturing parameters on tenacity of fibres. Those tests were performed with a wide range of strain rates. It was found that the fibres break at their weakest point, i.e. bond edge, in optimally bonded nonwovens. Additionally, failure stress and strain in tension of a fibre extracted from the fabric were significantly lower than those of virgin fibre. Since damage in nonwovens occurs by progressive failure of fibres, those experiments were used to establish criteria for damage initiation and propagation in thermally bonded nonwovens based on polypropylene fibres. Moreover, the results obtained from the experiments are useful to simulate the damage behaviour of nonwoven fabrics.

1. Introduction

A continuous growth in applications of nonwovens has led to a substantial increase in use of thermal bonding as compared to mechanical and chemical bonding processes for manufacturing of nonwovens since a higher production rate can be achieved by thermal bonding. Furthermore, it consumes the lowest amount of energy compared to other bonding processes with no hazardous substances involved as in chemical bonding. Therefore, thermal bonding is more suitable for the modern world with greater awareness of environmental impact [1, 2]. The growing demand for disposable and reliable products impels the research aimed at deformation and damage in low-density nonwovens. Thus, low-density

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thermally bonded nonwovens (planer density less than 50 g/m^2) are selected in this study to understand their damage behaviour.

In thermal bonding, fibres are passed through two hot calendar rolls under pressure; surface design of which can be smooth or have an embossed pattern. On embossed calendar rolls, bonding mainly occurs at raised areas resulting in bonded spots called “bond points”. As higher temperature is involved in thermal bonding, fibre properties are characterized by the temperature level (and variation) during this manufacturing stage. Depending on the manufacturing parameters related to bonding performance, there are three types of thermally bonded nonwovens: under-bonded, well-bonded and over-bonded. Nonwovens manufactured at optimal temperature range (150°C to 160°C) are called well-bonded, whereas bonding at lower and higher than optimal temperature is called under-bonding and over-bonding, respectively [3]. Other manufacturing parameters such as calendaring pressure and manufacturing speed also affect the performance of bonding in nonwovens [2, 4]. All the manufacturing parameters influence each other, and only a careful selection of optimal temperature with adequate levels of calendaring pressure and processing speed can produce a well-bonded fabric.

Many researches were conducted to investigate the effect of bonding temperature on mechanical performance of nonwovens and their fibres during thermal bonding. According to literature, most of the fibres fail at bond periphery in well-bonded and over-bonded fabrics due to a rapid change in molecular orientation of fibres at bond edge [5-11], leading to reduction in modulus and yield strength of fibres at the bond edge. All these studies emphasize the origin and reasons of fibre failure in thermally-bonded nonwovens in tension rather than quantifying the loss of strength in a single fibre in terms of stress and strain. From a fundamental viewpoint, it is important to quantify the change in maximum stress and corresponding strain for fibres in a thermally bonded nonwoven as failure of multiple fibres occurs before final failure of fabric. This phenomenon was the main objective of this study.

This paper focuses on experimental analysis of mechanical characteristics of polypropylene fibres used in low-density thermally bonded nonwovens with different basis weight. A novel experimental approach was followed in this study in a way that single fibres attached to individual bond points at their both ends were tested to analyse the effect of manufacturing parameters on failure stress and strain of single fibre.

2. Material

The material type used in this study is low-density — planer density less than 50 g/m^2 — thermally-bonded nonwoven, composed of mono-component polypropylene (PP) fibres (manufactured by FiberVisions, USA). Three different basis weights of fabric (20 g/m^2 , 30 g/m^2 and 40 g/m^2) manufactured at an optimal temperature of 156°C are used. Microstructure of the nonwoven material studied is shown in Fig. 1a. Apparently, these fabrics are composed of staple fibres having diameter of approximately $18 \mu\text{m}$ (Fig. 1b) with the length of 38.1 mm and linear density around 2.3 denier . All the fabrics have small rectangular-shaped bonds as shown in Fig. 1a.

3. Configuration of test samples

Test samples used in this study were single mono-component PP fibres utilised in manufacturing of low-density thermally bonded nonwovens. During manufacturing of this kind of nonwovens, web of fibres is passed through the hot calendars with engraved pattern on their surface. Fibres partially melt in respective regions and join together at a cooling stage. Molecular orientation of fibres changes from the bridging fibres into the bond in this manufacturing stage, ultimately leading to a decrease in the modulus and breaking strength of the fibres at bond edge. Thus, it is not possible to use the material properties of virgin fibres especially for damage analysis of the fabric. In this study, fibre samples were extracted from the fabric in a way that they are attached to individual bond points at their ends as shown in Fig. 2.

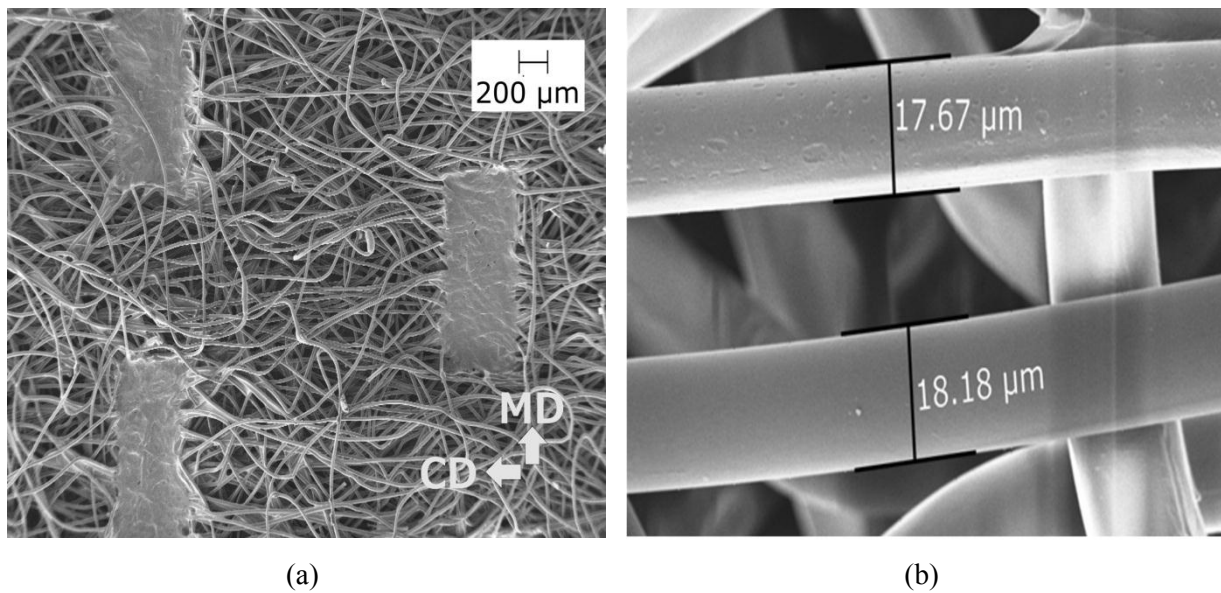


Figure 1. SEM image of thermally bonded nonwoven fabric (30 g/m² PP) (a); and its PP mono-component fibres (b)

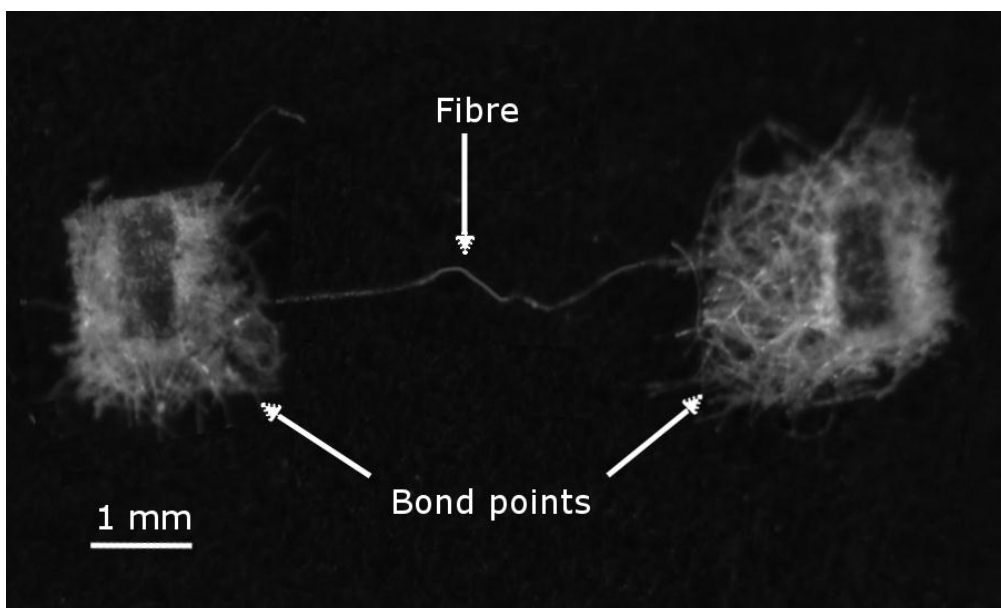


Figure 2. Single fibre attached to bond points at each end

Preparation of samples was tedious due to handling issues related to the size and softness of the specimens. In order to ensure removal of the fibres between the bond points so that only a single fibre is attached to two bond points at its ends, a magnifying glass was used. The single-fibre specimens were prepared without applying preload. To prevent slippage and dislocation of specimen during the tests, bond points at the edges of the fibre were attached to small pieces of cardboard with the help of a double-sided tape in such a way that the cardboard is as close to the edge of the bond towards the fibre

as possible so that the accurate stress-strain behaviour of the processed fibre is obtained without amalgamating it with that of bonds. Additionally, specimens of unprocessed or virgin polypropylene fibres used to manufacture these nonwovens were also prepared by employing the same technique. The length of the fibre specimens varied between approx. 3 mm and 6 mm as it is not feasible to control their length due to the specimen-preparation technique and orientation of fibres. The samples were clamped with special grips mounted on Instron® Micro Tester 5848 having the Instron® $\pm 5\text{N}$ high-precision load cell. A high-speed camera (Photron Fastcam SA3®) with advanced macro capabilities was used to make sure that fibre was not stretched during preparation and mounting of specimens. In addition to this, the camera was used to monitor the fibre to avoid slipping during the test. The complete arrangement of setup with the fibre mounted on tensile test rig is shown in Fig. 3. Fibre behaviour was determined by measuring the load continuously during the test along the cross-head displacement.

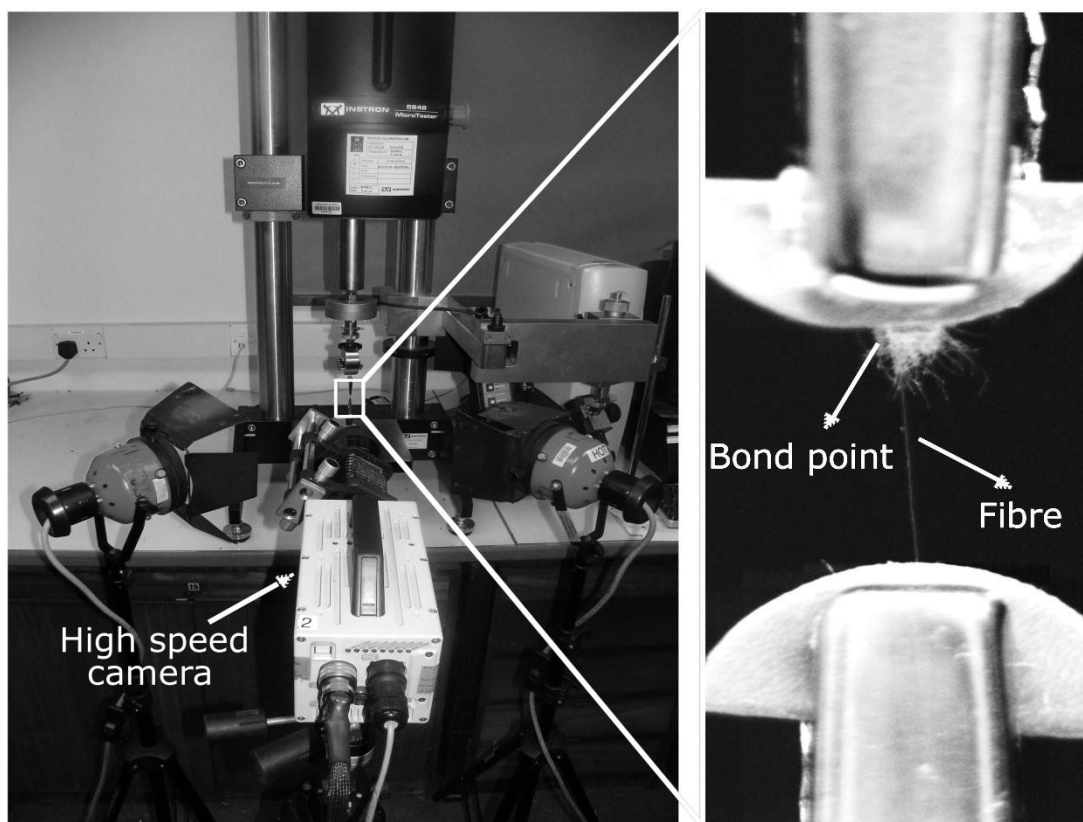


Figure 3. Test setup for fibre testing (Instron Micro Tester 5848; Photrom fastcam SA3)

4. Results and Discussions

Tensile tests were performed by stretching the fibre samples with three different levels of constant strain rates. Due to difficult control of the fibre's length, a constant strain rate $\dot{\epsilon}$ was achieved by modifying the velocity of the cross-head with respect to the current length of the fibre. The relationship used for this purpose is shown in equation 1.

$$\frac{v}{l} = \dot{\epsilon} = \text{const}, \quad (1)$$

Where V is the cross-head velocity and l is the length of fibre. Here, the constant strain rate corresponds to 0.01, 0.1 and 0.5 1/s. The tensile tests at each strain rate for processed and unprocessed fibres were repeated for at least ten times to assess the variability in results.

The fibre behaviour observed at different strain rates was similar to that of a typical polymer and is characterized by nonlinearity based on elastic and plastic stages as shown in Fig. 4. Variation of stress-strain curves with a change in the strain rate was due to viscous effects in the material. Those experiments did not result in a certain value of maximum stress and strain at maximum stress in fibres at any particular value of strain rate rather provided a range, within which these parameters fall. The mean values of these parameters with standard deviations are given in Table 1.

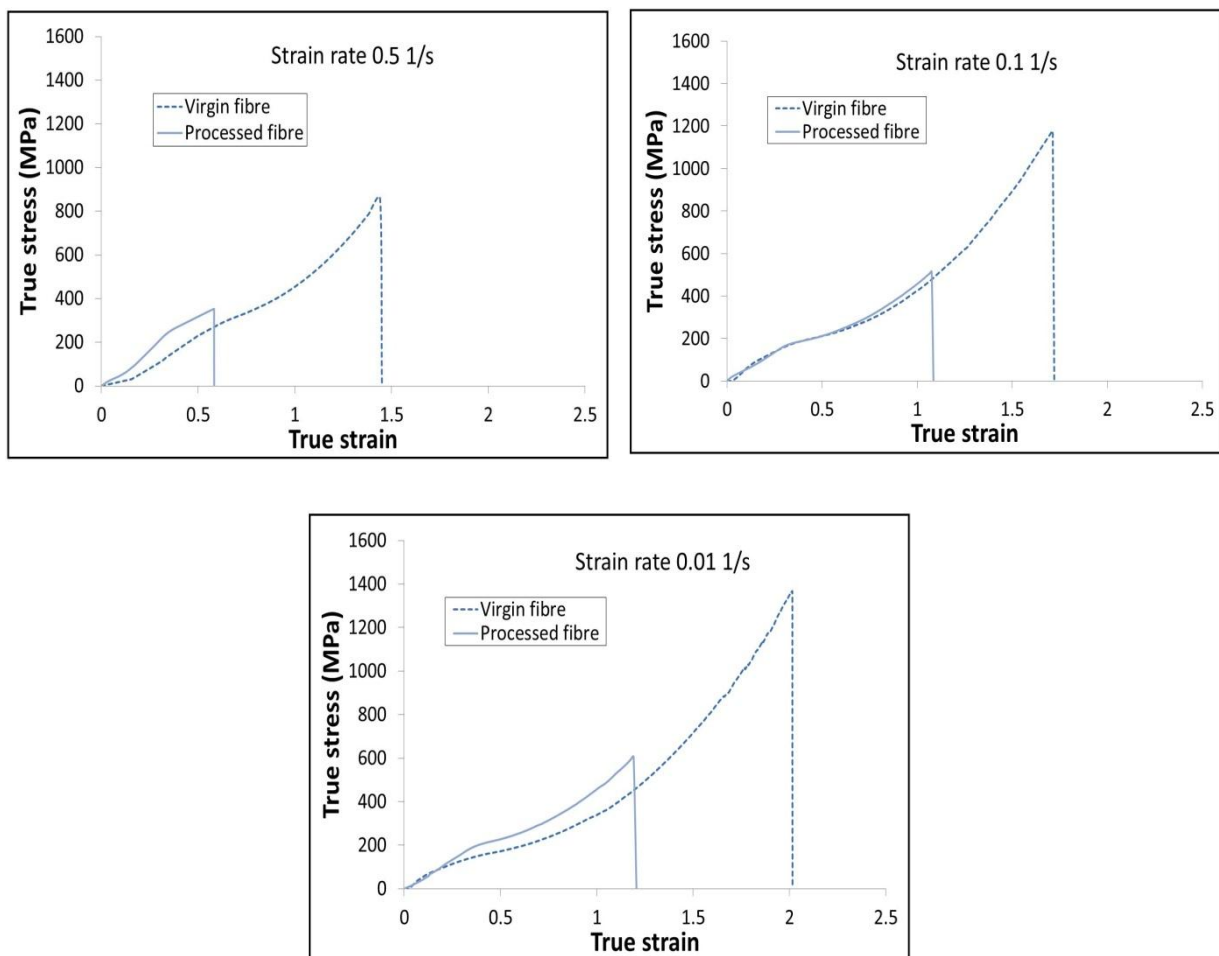


Figure 4. Mechanical behaviour of PP fibres at strain rate 0.05 1/s (a); 0.1 1/s (b); and 0.01 1/s (c)

A loss in tenacity of PP fibres due to manufacturing conditions of nonwovens can be analysed from the data given in Table 1. The data show that at optimum manufacturing parameters, the breaking stress of fibres decreased by some 64% and the corresponded strain decreased by 41%. This deterioration of performance of fibres in the fabric can be understood by examining the physics of bond formation. During thermal bonding, the fibres are pressed by the calendar rolls and thus weakened at the bond edge where the bond-point flattens the fibres due to calendar pressure. As this mechanical damage of fibres contributes almost negligibly to their loss of tenacity [10], therefore, the depth of bonding is not considered here. However, the temperature involved in thermal bonding causes the melting of fibres and diffusion of chain segment for bonding resulting in decrease of fibre strength.

Table 1. Mean values with standard deviation of failure stress and strain of virgin and processed fibres at various strain rates

	Strain rate (1/s)	Failure stress (MPa)	Strain at failure stress
0.01	Processed fibre	481 ± 48	1.29 ± 0.67
	Unprocessed fibre	1299 ± 95	2.93 ± 0.78
0.1	Processed fibre	315 ± 28	1.05 ± 0.11
	Unprocessed fibre	998 ± 57	1.77 ± 0.09
0.5	Processed fibre	240 ± 53	0.79 ± 0.1
	Unprocessed fibre	818 ± 60	1.49 ± 0.14

5. Conclusions

In this paper, a procedure for measuring directly the loss in tenacity of fibres in thermally bonded nonwovens was presented. Tensile tests at different strain rates were performed on carefully excised fibres from the nonwoven in a way that each fibre was attached to individual bond points at both ends. It was found that the breaking strength of polymeric fibres in the thermally bonded nonwoven at optimum processing conditions was less than that of virgin fibres. The failure stress of fibres and corresponding strain decreased by approx. 64% and 41%, respectively. The results reported here are in good agreement with the previous work [5, 6, 8, and 10]. The reason for the decrease in failure parameters of processed fibres is the rapid change in the orientation of their molecular chains at bond edge since the chains of polymers relax and diffuse due to high temperature and pressure during bonding process [5-11]. These molecular chain segments are cocrystallized to form the bond. The variation in failure parameters with strain rate is due to the viscous behaviour of PP fibres. The molecular chains in fibre are normally cross-linked which tend to stretch as result of uniaxial loading in tensile testing. The stretched conformation of the chains is not stable and chains tend to return their original upstretched form [14]. At higher strain rates, there is not enough time for the chain segments to regain their original form and fibres fail at lower level of stress and strain. During loading of nonwovens, rearrangement of fabric microstructure occurs due to reorientation of fibres in the direction of loading and more fibres start participating in load bearing. The fibres, with the applied stresses reaching their threshold, fail triggering damage in nonwoven. However, the complete failure does not follow immediately but occurs as a progressive failure of fibres [13]. Parameters of this continuous failure process realised in the fabric can be used to simulate the damage initiation and propagation behaviour of thermally bonded nonwovens.

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References

- [1] Russell, S. J. Handbook of Nonwovens, Woodhead Publishing Limited, 2007.

- [2] Albrecht, W.; Fuchs, H.; Kittelmann, W., W., Nonwoven Fabrics: Raw Materials, Manufacture, Applications, Characteristics, Testing Processes, Wiley-VCH, Weinheim, 2003.
- [3] Kim, H. S.; Deshpande, A.; Pourdeyhimi, B.; Abhiraman, A.; Desai, P. Textile Res. J. 2001, 71, 157.
- [4] Kim, H. S.; Pourdeyhimi, B.; Desai, P.; Abhiraman, A. Textile Res. J. 2001, 71, 965.
- [5] Wang, X.; Michielsen, S. Textil Res. J. 2002, 72, 394.
- [6] Michielsen, S.; Wang, X. Int. Nonwovens J. 2002, 11 (2), 35.
- [7] Dharmadhikary, R. K.; Davis, H.; Gilmore, T. F.; Batra, S. K. Textile Res. J. 1999, 69, 725.
- [8] Wang, X.; Michielsen, S. Textile Res. J. 2001, 71, 4251
- [9] Hedge, R. R.; Bhat, G. S.; Campbell, R. A. J. Appl. Polymer Sci. 2008, 110 (5), 3047.
- [10] Chidambaram, A.; Davis, H.; Batra, S. K. Inter Nonwovens J. 2000, 9 (3), 27.
- [11] Bhat, G.S.; Jangala, P.K.; Spruiell, J.E., J. Appl. Polymer Sci. 2004, 92 (6), 3593.
- [12] Michielsen, S.; Pourdeyhimi, B.; Desai, P., J. Appl. Polymer Sci., 2006, 99 (5), 2489.
- [13] Farukh, F.; Demirci, E.; Sabuncuoglu, B.; Acar, M.; Pourdeyhimi, B.; Silberschmidt, V.V., Comp. Mat. Sci., in press
- [14] Reusch, W. Virtual Textbook of Organic Chemistry, 1999, Available at <http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/intro1.htm>