ESEM study of tensile behaviour of spunbonded bicomponent fibre nonwovens

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The tensile behaviour of polyethylene/polypropylene (PE/PP) bicomponent fibre spunbonded nonwovens has been studied using an environmental scanning electron microscope (ESEM). A tensile stage, mounted in the ESEM, was used to examine the dynamic process of the PE/PP bicomponent fibre spunbonded nonwovens at different stages of deformation. The visual information obtained through the ESEM provides clear evidence of relevant mechanism of nonwoven deformation. The study shows that the ESEM is a powerful tool for examining the dynamic tensile behaviour of different materials.

Keywords: Bicomponent fibre, Nonwoven, Polyethylene, Polypropylene, Tensile behaviour
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1 Introduction
Spunbonding is one-step web forming technology, which involves deposition of spun filaments onto a collecting conveyor in a uniform random manner followed by bonding the fibres. Since the fabric production is combined with the fibre production, the process is generally more economical than the processes using staple fibre to make nonwovens1. The demand for high performance nonwovens in the wide range of applications has promoted innovations in spunbonding process. Bicomponent fibre technology has been successfully applied in the spunbonding process to produce nonwovens with unique properties and better performance2.

Spunbonded bicomponent fibre nonwovens are composed of two polymers. A lower melting polymer acts as a sheath covering over a higher melting core. Bicomponent fibre technology applied in spunbonding process has been developed to improve the properties of spunbonded nonwovens for high performance applications. These new applications require the nonwovens to be engineered very carefully and precisely since their failure could have fatal consequences (e.g. civil engineering).

To better understand bicomponent fibre on its properties, it is necessary to gain as much information as possible about the fibre microstructure at all stages of production and hence better structure/property relationships. Our objective is to develop a technique to examine the damage progression and failure strength of the bicomponent fibre spunbonded nonwovens from the knowledge of constituent fibres and the fibre web structure.

Environmental scanning electron microscope (ESEM) is a new development in the microscopy technology, which is able to image dry, wet, oily and outgassing samples in their natural state due to the presence of gas molecules in the chamber. Specimens observed in the ESEM do not need to be coated with a conductive layer, thereby ESEM offers the possibility to perform in situ mechanical testing and observations. In the present study, the installation of a tensile stage into the chamber of an ESEM was used to examine the process of tensile deformation of the bicomponent fibre spunbonded nonwovens at high magnification and in real time.

2 Materials and Methods
2.1 Materials
Polyethylene/polypropylene (PE/PP) bicomponent spunbonded nonwovens were used for the study. The lower melting polymer PB can function as a sheath binder covering over the higher melting core of PP.
The materials obtained from production line were characterized in the laboratory based on BS EN 29073 standards. The details of the materials used are given in Table 1.

2.2 Equipment

The instrument Philips ESEM XL 30, which is specifically designed to be able to examine the details of samples in their natural state by means of a differential pumping system and gaseous secondary electron detector, was used for the study. The differential pumping system enables the electron gun and upper parts to be held at high vacuum of $10^{-6} - 10^{-7}$ Torr, while the pressure in the specimen chamber can be maintained up to 20 Torr (ref. 4).

The gaseous secondary electron detector amplifies the signal generated by secondary electrons. The electrons collide with the gas molecules in the chamber, resulting in emission of more electrons and ionisation of the gas molecules as they travel through the gaseous environment. The positively charged gas ions are attracted to the negatively biased specimen and offset charging effects. Therefore, an ESEM is able to examine wet, oily and outgassing samples without coating.

A tensile stage (Ernest F Fulham, 100 lb), fitted within the ESEM, was used to test the specimens. The tensile stage was mounted in the observation chamber. Samples were mounted horizontally and then clamped to a pair of jaws. When the tensile force was applied, a dual threaded leadscrew drove the jaws symmetrically in opposite directions, keeping the sample centred in the field of view. A computer interface and data logging were used to record the results, which were presented in the form of load extension curves.

2.3 Experimental Procedure

The nonwoven specimens were cut into the size of 40mm x 10mm (machine direction - MD) and then mounted on the tensile stage in the ESEM chamber. The microscope was pumped down and flooded with water vapour up to 0.5 Torr pressure, leaving the specimen relatively dry. The beam voltage was kept as low as 20 keV in order to avoid beam damage to the materials.

Tensile tests were performed at room temperature with an extension rate of 5.7 mm/min. The deformation process and fracture surface morphology were video recorded in real time.

<table>
<thead>
<tr>
<th>Table 1—Bicomponent fibre nonwovens</th>
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<td>Sample</td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Bonding</td>
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<tr>
<td>Mass, g/m²</td>
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<tr>
<td>Thickness, mm</td>
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<td>Fibre diam, μm</td>
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3 Results and Discussion

3.1 Tensile Behaviour

The tensile curves for Nonwoven A and Nonwoven B are shown in Fig. 1. Significant stress develops at very low elongation. The force increases sharply as the fibre web is stretched. Final failure of these specimens occurs at a lower average elongation (<30%). Although the tensile strength of Nonwoven B is much higher than that of Nonwoven A, both have very similar elongation of about 25%. This implies that both the fabrics follow the similar breaking mechanism. The dynamic deformation process was followed by the ESEM observation.

3.2 Development of Nonwoven Deformation

The development of nonwoven deformation was observed in the ESEM in real time. As shown in Fig. 2(a), the Nonwoven A is the fibrous web with a random distribution of fibre orientations. It can be observed that at high magnification the fibres are bonded at the fibre intersections [Fig. 2(b)]. The ESEM images also reveal that the fibres have rough surfaces, which is believed to be caused by the heating and cooling during the manufacturing process.
As the extension is applied, the fibres in the fabric start moving towards the loading direction. The series of the ESEM images (Fig. 3) show the progress of tensile deformation of Nonwoven A. The randomly distributed fibres in the web are tightened and strengthened as the loading force is applied [Fig.3(a)].

As the extension is increased, the deformation at the bonding points restrains the movement of bonded fibres, resulting in the fibre bending in the web [Fig.3 (b)]. Some weak bonds are broken and the fibres move towards the loading direction as the extension is further increased. The fibres slip past over one
another from the bonded positions and move towards the loading direction [Fig. 3(c)]. The web collapses with the further increase in extension. Web failure initiates by fibre breakage at the weakest bonding point and rapidly expands across the web, resulting in the fast movement of fibres along the loading direction [Fig. 3(d)]. It can be clearly seen that the fibre orientations have been significantly changed.

The ESEM images (Fig. 4) reveal the debonded surfaces at fibre intersections. Bonded layers are

![Fig. 4—Morphology of the debonded surfaces (A) peeled part of PE sheath, and (B) core of polypropylene](image)

![Fig. 5—Tensile deformation in sample Nonwoven B (A) at 0% elongation, (B) at 15% elongation, and (C) at 25% elongation](image)
either peeled off from the other fibres at the bonding points [Fig.4(a)] or taken off by the other fibres [Fig.4(b)]. It can be seen that the separation of the sheath-bonding layer is the major mechanism of web deformation. Fig.4(b) also reveals the smooth surface of the PP core, indicating that there is no interaction between the sheath and the core. It is believed that the strength would be improved if the bonding exists between the sheath and the core.

The ESEM observation also indicates that the Nonwoven B has the similar behaviour under loading force (Fig. 5). Fig. 5(a) reveals that the Nonwoven B has the dense fibre distribution due to the higher mass per square meter. The random distribution of fibres in the web with bonding at fibre intersections and the rough surfaces can also be seen in the image. The deformation shown in Fig.5 (b) clearly shows the behaviour of fibres in the web under force. The collapsed web [Fig.5(c)] shows the separation of bonding layers and the smooth PP core fibres.

4 Conclusions
This study has explored the use of the environmental scanning electron microscope (ESEM) for the dynamic examination and observation of the tensile behaviour of the bicomponent fibre nonwovens. The ability of the ESEM to follow dynamic events under a variety of conditions gives new insight into the kinetics of structure formation, interfaces and structure rearrangement that are important for the processing and product development in textile research and engineering.

References