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PREPARATION AND PROPERTIES OF COTTON-EASTAR BIODEGRADABLE/COMPOSTABLE NONWOVENS

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Abstract

As biodegradable/compostable cotton-based nonwovens are sustainable materials, there is increasing interest in them, with the expansion of nonwovens into novel applications. Over the past few years, research has been done at the University of Tennessee, Knoxville to produce and evaluate nonwoven products containing cotton with different thermoplastic binder fibers. Nonwoven fabrics manufactured from cotton and Eastar, a biodegradable thermoplastic fiber have shown great promise. The production of nonwovens by the thermal bonding process from such compositions, and the structure and properties of the resulting products are investigated. The results have shown that, by appropriately selecting the combination of fibers and process conditions, nonwoven fabrics with good performance properties can be produced.

Introduction

In recent years, nonwoven fabrics have been widely used in many applications including, home furnishings, automotive industry, civil engineering, geotextiles, industrial filters and medical sanitary materials. More than 50% of these nonwoven fabrics are disposable products [1]. Majority of these products are made of synthetic fibers, such as polypropylene, polyethylene, polyester and polyamide, which are not biodegradable and end up as solid waste. With the growing environmental awareness throughout the world, environmentally compatible nonwoven products have been receiving increasing attention in recent years [2, 3].

Cotton-based biodegradable/compostable nonwovens become a major choice, due to the good properties of cotton fibers, such as biodegradability, softness, absorbency and breathability. Cellulose Acetate (CA) fiber has shown to be a good binder fiber for cotton-based biodegradable/compostable thermal calendered nonwoven products by the University of Tennessee, because it is a thermoplastic, hydrophilic and a biodegradable fiber. However, the softening temperature of cellulose acetate fiber is relatively high (T_s: 180-205˚C), even in the presence of some kinds of internal and/or external plasticisers [4,5]. Recently Eastman Chemical Co. developed the Eastar *Bio*® GP copolyester unicomponent (Eastar) [6, 7] fiber, which can be totally degraded into CO_2, H_2O and biomass. Eastar unicomponent fiber and an Eastar *Bio*® GP copolyester bicomponent (Eastar/PP) fiber were selected as binder fibers to make thermal calendered nonwoven products. Another advantage of these binder fibers is their relatively low melting temperature (110˚C) of the Eastar component.

The effect of some key processing variables, such as blend ratio and bonding temperature, was studied. Preparation and the structure and properties of cotton/Eastar nonwoven fabrics are discussed in this paper.

Experimental

Fiber Selection and Properties

The cotton fiber used in this research was supplied by Cotton Incorporated. The scoured and bleached commodity cotton fiber had a moisture content of 5.2%, a micronaire value of 5.4 and an upper-half-mean fiber length of 24.4 mm (0.96 inch). The Eastar *Bio*® GP copolyester unicomponent (Eastar) and bicomponent (Eastar/PP) staple fibers selected for this study were produced by Eastman Chemical Company. The bicomponent fiber has a sheath/core structure, with Eastar *Bio*® GP copolyester as the sheath on a stiffer core, in this case, polypropylene.

Processing

The important steps in the processing are shown in Figure 1. Fibers were first opened by hand and then weighed according to the desired blend ratio and fabric weight. The fiber blend was then carded to form a web using a modified Hollingsworth card. The resulting carded fabric weights were around 40 grams/m^2. The carded webs were then thermally point-bonded using a Ramisch Kleinewefers 60 cm (23.6 inches) wide calender with a bonded area of 18 %. Two blend ratios (70/30 and 50/50 of Cotton/Binder fiber), three calendering temperatures (100 °C, 110 °C, and 120 °C), and two nip pressures (0.33 MPa, and 0.4 MPa) were used. All the webs were calendered under the same line speed of 10 m/min.

Characterization of Fiber and Nonwoven Fabrics

Tensile properties of single filament and nonwoven fabrics were tested according to ASTM D 3822-91 Standard Test Method for Testing for Fiber/Filament and ASTM D 1117-80 Standard Test Method for Tensile Testing of Nonwoven Fabrics respectively. All the tensile tests were carried out under the standard atmosphere for testing textiles, the temperature of 21 ± 1 °C and the relative humidity of 65 ± 2 %.

Thermal analysis of the binder fibers was done using the Mettler DSC-821 machine at a scanning rate of 20°C/min.

Basis weight of nonwoven fabrics was determined according to *INDA Standard Test 130.1-92 Standard Test Method for the Mass Per Unit Area of Nonwoven Fabrics*.

Scanning Electron Microscopy (SEM) pictures were taken for bonding points and failure structure under a Hitachi S - 3500 N Scanning Electron Microscope. 20.0 KV electronic beam, 50 MPa vacuum, and a magnification of 80 were used for the images.

Results and Discussion

Fiber Properties

Physical properties of all the fibers used in this research are listed in Table 1. The data show that the tenacity or peak strength of Eastar unicomponent (Eastar) fiber is comparable to that of cotton fiber, while the tenacity or peak strength of Eastar bicomponent (Eastar/PP) fiber is much higher than that of cotton fibers, for the peak extension of both Eastar unicomponent and bicomponent fiber are much higher than that of the cotton fibers.

DSC scans of Eastar staple fibers are shown in Figure 2. The melting temperature of the fiber is around 110°C. This is much lower than that of the fibers that have been investigated as binder fibers. Based on this, thermal calendering temperatures to be used will be relatively lower.

Processing

Carding is the most common process to produce nonwoven fabrics from staple fibers. The objective of carding is to disentangle the fiber stock into individual fibers with minimum fiber breakage. For cotton-based thermally point-bonded nonwovens, it is important that the low-melting binder fiber be distributed evenly throughout to ensure uniformity of fabric properties. However, the carded webs always have area irregularities of mass distribution caused by machine variables (the nature and conditions of card clothing, the relative speeds and settings of the carding elements) and fiber properties, such as staple length, stiffness, crimps, fiber tensile properties, and fiber finishes etc. One disadvantage in using Eastar unicomponent as-spun fiber as a binder fiber is that it is hard to get the binder fibers well distributed due to the high elasticity of the fiber (shown as high peak extension of 144.0 % in Table 1), which leads to low tensile properties of the final nonwoven fabrics. So a bicomponent fiber, Eastar/PP, with Eastar *Bio*® GP copolyester as the sheath, and polypropylene as the stiffer core was selected as the binder fiber instead of Eastar unicomponent fiber to improve the processability and the tensile properties of the final fabrics.

Effect of Eastar Fiber Component and Bonding Temperature on Peak Load of Cotton/Eastar Nonwovens

The effect of Eastar fiber component and bonding temperature on the peak load of Cotton/Eastar and Cotton/(Eastar/PP) nonwovens along machine direction can be seen from the data in Figure 3 (a, b) respectively. With the increase of Eastar and Eastar/PP binder fiber component, peak load increases. This is the result of the increase in binder fiber, which causes increases in the number of bond points and the effective bond area. However, at a higher bonding temperature (120°C), the peak load decreases with the increase in binder fiber. This may be caused by the different failure mechanism of the fabrics bonded at higher temperature.

Failure of nonwoven fabrics can occur by the failure of the fiber (fiber breakage), failure within the bond (bond breakage or cohesive failure) or at the fiber-binder bonding interface, or by a combination of these modes [8-9]. The interaction of component properties, structure, and fabric deformation mechanisms can lead to a variety of unique failure mechanisms for nonwoven fabrics. The nonwoven fabric failure mechanism is influenced by fiber physical properties, adhesive properties, and structural properties including the relative frequency and structure of the bonding elements, fiber orientation and the degree of liberty of movement of the fibers between the bond points. Physical properties of the nonwoven will be controlled by the first failure occurring in the fabric sample [10]. Based on this, it is obvious that the failure mechanism of nonwoven fabrics bonded at a higher temperature is different from that of the nonwoven fabrics bonded at lower temperature. This difference in failure mechanism can be clearly seen by the SEM pictures of the failed structures of the fabrics produced with different binder fiber compositions (Figure 4). These observations are consistent with those of Gibson and McGill [11], who have studied the failure mechanism of thermal point-bonded polyester nonwovens as a function of the bonding temperature. At lower bonding temperatures, the bond failure mechanism was found to be the loss of interfacial adhesion at the bond site leading to bond disintegration; at higher bonding temperatures, the failure mechanism was cohesive failure of the fibers near the bond periphery.

By comparing Figure 3(a) with Figure 3(b), one can see the advantage of using Eastar bicomponent binder fiber. At the two blend ratios cotton/binder fiber around 70/30 and 50/50, and the three bonding temperatures (100 °C, 110 °C, 120 °C), the peak loads of Cotton/(Eastar/PP) nonwoven fabrics are much higher than that of Cotton/Eastar nonwovens. The reason is that Eastar unicomponent as-spun fibers were not well distributed in the carded webs due to the high elasticity of the fiber (high peak extension and low modulus (seen in Table 1)), which leads to low tensile properties of the final nonwoven fabrics. However, for Eastar/PP bicomponent fiber, the elasticity of the binder fiber has been greatly decreased by introducing polypropylene as the stiffer core. Therefore, using Eastar/PP bicomponent fiber as a binder fiber can improve the tensile properties of Cotton/Eastar nonwoven fabrics. This improvement in tensile properties is the result of better binder fiber properties as well as the improved processing characteristics of the modified binder fiber.

Based on the above, high strength Cotton/(Eastar/PP) nonwoven fabrics can be produced by using Cotton/(Eastar/PP) at a blend ratio of 50/50, thermal calendered at 110°C under 0.4 MPa pressure. In fact the tensile properties of Cotton/(Eastar/PP) nonwoven fabrics were found to be comparable to, or better than that of Cotton/Cellulose Acetate nonwovens [12].

Summary

Binder fiber component and calendering temperature are the two main variables, which determine the properties of thermal bonded nonwovens. Peak load increases with increase in binder fiber component. With the increase in bonding temperature, peak load first increases at lower bonding temperature. It is the result of the formation of better-developed bonding structure. However, at higher bonding temperatures (e.g. 120°C), the peak load decreases with the increase of bonding temperature. This may be caused by the different failure mechanism of the fabrics bonded at higher temperature.

Good quality cotton-based nonwoven fabrics can be made using Eastar/PP bicomponent binder fiber under lower calendering temperature (around 110°C). Peak load of Cotton/(Eastar/PP) nonwoven fabrics are much higher than Cotton/Eastar nonwoven fabrics. High strength Cotton/Eastar nonwoven fabrics can be produced by using Cotton/(Eastar/PP) at a blend ratio of 50/50, thermal calendering at 110°C under the pressure of 0.4 MPa with a calendering speed of 10 m/min with better process ability.

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Table 1. Properties of selected fibers (single filament).

	Cotton	Eastar	Eastar/PP
Filament density (g/cm^3)	1.5	1.2	1.1
Filament linear density (tex)	0.24	0.44	0.44
Peak extension (%)	5.4	144.0	96.0
Peak strength (mN/tex)	152.2	138.0	269.6
Initial modulus (mN/tex)	360.9	204.6	392.5
Staple length (inches)	0.96*	1.0	1.5
Crimps	more	less	more

* upper-half-mean fiber length

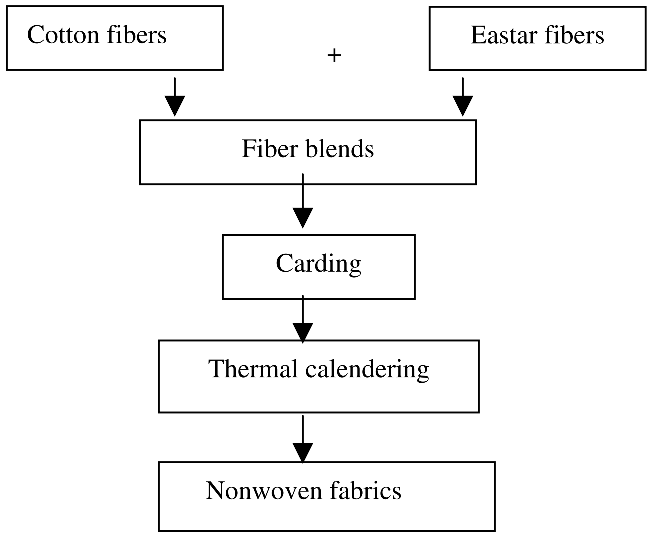


Figure 1. Flow chart of processing procedures.

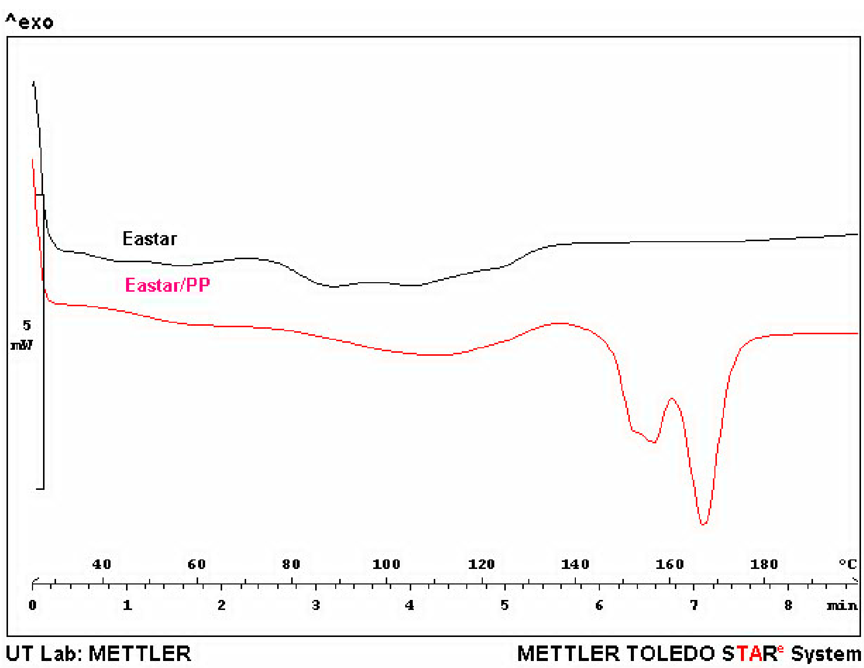
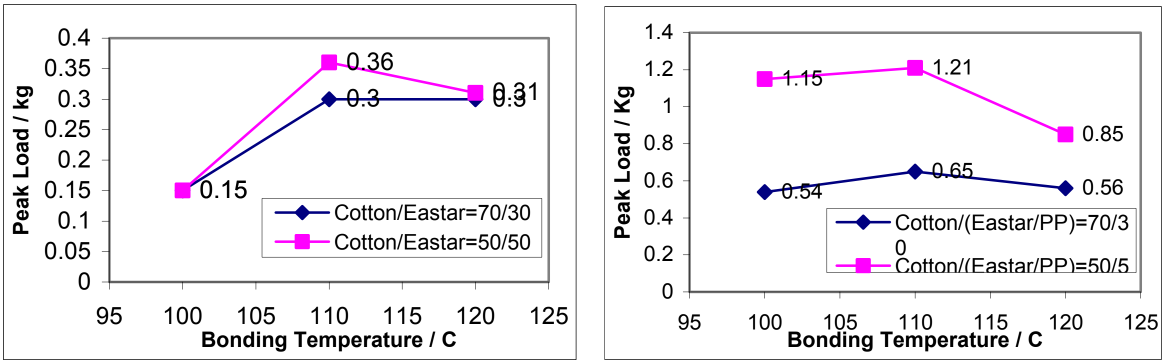


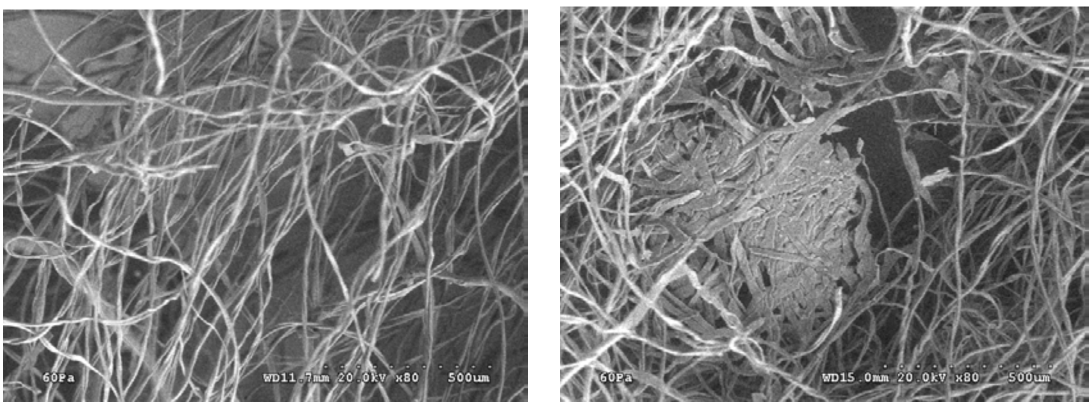
Figure 2. DSC scan of Eastar staple fiber (heating rate 10°C/min).



(a) Cotton/Eastar
Calendering Pressure = 0.33 MPa
Calendering speed = 10m/min
Fabric weight: ~ 40g/m^2

(b) Cotton/(Eastar/PP)
Calendering Pressure = 0.4 MPa
Calendering speed = 10m/min
Fabric weight: ~ 40g/m^2

Figure 3. Effect of Eastar Fiber Component and Bonding Temperature on Peak Load of Cotton/Eastar Nonwovens.



(a) Bond disintegration during break
Cotton/(Eastar/PP) = 70/30
Bonding Temp = 100°C
Calendering Pressure = 0.4MPa
Calendering speed = 10m/min
Fabric weight: ~ 40g/m^2

(b) Failure of the fibers near bond site
Cotton/(Eastar/PP) = 70/30
Bonding Temp = 120°C
Calendering Pressure = 0.4MPa
Calendering speed = 10m/min
Fabric weight: ~ 40g/m^2

Figure 4. SEM photographs of failure structure after tensile testing for Cotton/(Eastar/PP) nonwovens.