Development of Nursing Care Sheets of Cellulosic Nonwoven Fabrics for Ageing Society

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ABSTRACT

For care of the elderly in a rapidly aging society, a new type of nonwoven fabric care sheet made from cellulosic fibers laminated with a plastic film has been developed. Fiber orientation, friction, tensile strength, local deformation distribution during a tensile test and water absorbency were examined, with a view to practical application. The best fiber mixture ratio in the trial sheets was concluded to be 75% Manila hemp and 25% rayon fibers. In comparison with a linen cloth the addition of rayon fibers at about this ratio gives the most satisfactory properties in terms of soft touch and sensory smoothness to the nonwoven fabric as well as not being slippery. It also gives relatively high water absorbency and moderate elongation under tensile force providing shock-resistance, in spite of a rather low tensile strength, to the nonwoven fabrics using a pattern-matching technique has been developed and demonstrated. Using this method it was found that, during tensile deformation in the machine direction, the addition of rayon fibers allows even elongation in that direction but increases contraction in the cross direction.

KEY WORDS

Care sheet, Friction, Hydroentangled nonwoven fabrics, Manila hemp, Rayon, Pattern matching, Tensile deformation distribution, Water absorbency

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INTRODUCTION

Senior care is one of the important issues of modern society. Especially in Japan, aged people are commonly cared for at home by their family. Family caregivers are usually also aged and reduction of the burden is an emergent issue. As a paper-like cellulosic material, a new type of nonwoven fabrics sheet for the purpose of nursing care was investigated and developed. The target of our new composite material is a disposable bed sheet with water absorbing property on the nonwoven side and waterproofing property on the laminate film side. In comparison to some synthetic fibers, cellulosic fibers can provide comfort in contact with skin owing to their abundant water absorbency and retention of moisture, with which vomit, urine, perspiration are assumed practically. So, this material can be applied to any type of bedside care other than senior care. As raw fiber materials, a mixture of Manila hemp and rayon fibers was used. To evaluate the trial care sheets, we examined fiber orientation, friction, tensile strength, local deformation distribution during a tensile test and water absorbency.

In particular, image analysis for local deformation distribution is a unique way to analyze tensile behavior. Some researchers have investigated tensile deformation using image analysis techniques such as texture analysis to identify properties of nonwoven fabrics. Kim et. al [2] recorded video images of thermally bonded nonwovens from polypropylene fibers during tensile deformation and calculated changes of fiber orientation distribution function by image analysis. They revealed that fiber reorientation progresses during elongation more noticeably in the Cross Direction (CD) than in the Machine Direction (MD). Fiber reorientation depends on the anisotropy of the structure and the bond pattern. Thorr et. al [6] designed a sensor capable of locally measuring the mass per unit area of nonwoven geotextiles using illumination of an integrating sphere. By using texture analysis, they calculated energy for homogeneity degree, entropy for disorder degree and inertia for local variation degree from co-occurrence matrices. They also exhibited that the orientation distribution curve corresponded well to the vertical orientation in progress of fibers during a tensile test of a needle-punched nonwoven. Berkalp et. al [1] used contrast, namely, inertia functions calculated from the co-occurrence matrix and power spectrum for texture analysis of fabrics hydroentangled at different pressures.

The method we applied in this work is different from those described above and allows calculation of displacement of every block in a virtual grid imposed on images of a nonwoven fabric. Compared to mean changes over the whole area like fiber orientation distribution, measurement of displacement of actual individual blocks is characteristic of this method, and the purpose of this work includes this measurement in addition to the evaluation of the trial care sheets of cellulosic nonwoven fabrics.

EXPERIMENTAL

Materials

Manila hemp fibers and rayon fibers were used to prepare nonwoven sheets. Manila hemp fibers were unbeaten and had a mean length of 3.0 mm and a mean width of about 15 μ m. Rayon fibers had a mean length of 6.0 mm and a mean width of about 10 μ m. To prepare care sheets, plastic films of polyurethane and low-density polyethylene were used for laminating nonwoven fabrics.

Care sheet preparation

A pulp web was formed from the cellulosic fibers on the forming part of a pilot paper machine, hydroentangled at the end of that part and dried on a drum dryer continuously. The orifice of the water jet device was 0.1 mm in diameter and the jets were aligned at intervals of 1.0 mm. The hydraulic pressure was 0.98 MPa at the first manifold and 3.92 MPa at the second manifold. The nonwoven webs were laminated with a plastic film in a process separate from the nonwoven forming line. **Table 1** shows manufacturing conditions and properties. For comparison in frictional properties, a commercial product made from wood pulp fibers with a polyethylene laminate, i.e. Water protection sheet, Cellcomb AB, Sweden, was also measured. In prior to the following tests, every sample was conditioned at 23 °C and 50 % relative humidity.

Fiber orientation

The fabric structure was examined in terms of fiber orientation by X-ray diffractometry. Cellulose crystal face (004) is aligned in perpendicular to the fiber axis because cellulose molecules are aligned in parallel to the fiber axis. In this method, this property was used to determine fiber orientation from the diffraction peak intensity. For in-plane orientation measurement, five overlapped sheets of the fabrics were mounted as a sample so that the fabric plane was perpendicular to the plane of the incident and reflected X-ray beams. Radiation was impinged on one side of the sample and was reflected to the other side so that the X-ray beam passed transversely. The sample was rotated in its plane while the angle formed by the sample plane and the incident X-ray beam was maintained. The degree of fiber orientation was defined from area of (004) peak due to the crystal part (A) and base line area due to the amorphous part (B) as A/(A+B). X-ray diffraction patterns were recorded in the 30 to 40 degrees of 2θ range with X-ray source from Cu-K α target using a X-ray diffractometer (RINT2000, Rigaku Corporation, Japan).

Tensile test and local deformation distribution

Care sheets in use are subject to a wide variety of forces and, in particular, to tensile force. To evaluate mechanical strength and durability of the nonwoven fabrics, tensile strength and elongation were measured following ISO 9073-3:1989 except that the width and span of test pieces were 15 mm and 100 mm, respectively. Ten test pieces were tested and the load elongation curves with the results closest to the mean values were shown in the graph.

In-plane local deformation distribution during a tensile test was also determined using a

pattern matching application developed in the laboratory of Univ. of Tokyo [4]. This prototype system consists of a conventional tensile tester (UTM-100-, Orientec, Japan), a CCD camera (XC-77, SONY, Japan), an electric bulb for illumination at a low angle and the software for image capture and image analysis. In pattern matching, one of two images to be compared was divided into small rectangular blocks. The post-deformation image was searched for a block with a similar pattern to a certain block of the initial image taken as a template block while the block frame is moved pixel for pixel. The similarity S_{fg} is judged based on the inner product of the two block images as a vector according to Equation 1.

$$S_{fg} = \frac{\iint f(x, y)g(x, y)dxdy}{\sqrt{\iint \left|f(x, y)\right|^2 dxdy \iint \left|g(x, y)\right|^2 dxdy}}$$
(1),

where f(x, y) and g(x, y) mean gray levels at each coordinate (x, y) of the two block images f and g, respectively. A five-fold interpolation with the high-resolution bi-cubic spline interpolation function [5] was applied to determine the deformation distribution with five-fold resolution.

Image capture was achieved on nonwoven fabric samples without a plastic laminate cut to 15 mm in width. Five test pieces were subjected to the tensile test mentioned in the following way. A test piece was clamped with a span of 50 mm. The recorded region was almost 12 mm in width by 9 mm in height. Low angle illumination was used for emphasizing light and shade due to undulating fabric surfaces. The test piece was elongated at 10 mm/min to 1.96 N load and the elongation was stopped. Then, concurrent with restarting elongation, reflected surface images were recorded every 0.5 s for about 15 s. Recorded images had a resolution of 640 by 480 pixels. In analysis, the initial bitmapped image, namely, immediately after the cease at 1.96 N was set to time 0 and displacement of every 8 by 8 pixels block were calculated. In the case that displacement a certain block is too large to detect the exact destination after a long time of elongation, judgment was made according to how much its vector is similar in length and direction to those of its eight adjacent blocks. Test pieces were clamped between the upper fixed clamp and the lower movable clamp, so a downward shift of the whole captured image was observed with every sample. In the diagram of local deformation distribution, the displacement of the top center block was set to zero and the relative displacement of every block to that of the top center block was determined. In results, diagrams of local deformation distribution comprising many arrows were superimposed on video images at elapsed times of 5 s or 10 s. Arrows were drawn so that the length was five times as long as true displacement. Influences of fiber mixture ratio and tensile direction, that is, MD or CD were examined.

Frictional properties

On the assumption that the care sheets would be used for bedridden elderly, friction between

plain-woven bed linen and the care sheets was measured with a sensory friction tester, KES-SE (KatoTech Co., Ltd., Japan). To measure tactile quality of the nonwoven fabrics, a wire-wound contact object was used as an opposite material. The wire was wound at similar intervals to that of fingerprints. To measure coefficients of friction between a bed linen cloth and the nonwoven fabric side or film side, a plain-woven bed linen cloth made from 65 % polyester and 35 % cotton with a thread count of 140 in the frictional scan direction was mounted on the wire-wound contact object. Eight test piece pairs were tested.

Water absorption properties

The rate of water absorption through a slit of 1mm by 5 mm was determined. The water supply head with the slit was mounted on a fabric surface. Transferred water volume was measured by tracing movement of the meniscus formed in a glass capillary connected with the head as the opposite end. This apparatus named Automatic Scanning Absorptometer (Kumagai Riki Kogyo, Japan) was originally developed as a spiral-scan Bristow apparatus [3]. In this work, however, the head was kept on the same location of the fabrics and transferred water volume was recorded continuously. Four test pieces were tested for each sample.

RESULTS AND DISCUSSION

Figure 1 shows X-ray diffraction patterns of nonwoven fabrics mounted at different rotation angles in the plane of the fabrics. At 90 degrees, that is, when MD of the fabric was in the plane of the incident and reflected X-ray beams, (004) peak exhibited the highest intensity. As the fabric was rotated and its CD approached the X-ray plane, the peak intensity decreased. This result means that the water jet rearranged fibers so they ran in the direction of the web processing although the web had been actually a handsheet with no fiber orientation. The mechanism seems to be that the water jet drags and pushes apart fibers just like a needle working mechanically.

Figure 2 shows a comparison in fiber orientation between the nonwoven fabric and copy paper as a representative of common paper. The distance from the graph origin to each data point indicates the relative intensity of fiber orientation at each angle. The degree was lower for the fabric at all of the angles merely due to a different absolute mass of fibers involved in the X-ray diffraction measurement, but the MD/CD ratio was coincidentally very similar between them. Consequently, water jet entanglement was found to orient fibers in the direction of the processing.

Figure 3 shows kinetic coefficient of friction (MIU) and its mean deviation (MMD) between nonwoven surface and the fingerprint contact object. The MIU tended to decrease with increase in Manila hemp ratio while the MMD significantly increased with it. Soft fibers, that is, rayon in this case, are considered to give high friction because soft surfaces under load deform easily to interlock with stainless wires of the fingerprint contact object. However, nonwoven fabrics surfaces made from Manila hemp fibers have periodically-aligned openings more distinctly in MD than those including rayon fibers. These openings of rigid fibers are difficult to deform and are likely

to give periodic variation to friction. Consequently, addition of soft rayon fibers can give soft touch and sensory smoothness to nonwoven fabrics as well as non-slipperiness.

Figure 4 shows MIU of surfaces of nonwoven fabric side and the two kinds of laminate film side. The nonwoven fabric surface rich in rigid Manila hemp fibers gave a high MIU value against a bed linen cloth as well as against the fingerprint contact object shown in the previous figure. But, irrespective of the Manila hemp ratio, its MIU values were lower than those of the polyethylene film and much higher than those of the polyurethane film. This result implies that polyurethane-laminate care sheets slip on bed linen very easily, but polyethylene-laminate sheets slip less on bed linen when the care sheets are used with the nonwoven fabric side in contact with a garment. This tendency agreed with a result of the subjective test using the sense of touch by 10 examinees. The MIU value of the polyethylene side of the commercial product was lower than expected, possibly due to the rigidity of high-density polyethylene used as a laminate film.

Figure 5 shows mean values of tensile breaking strength of the nonwoven fabrics with different fiber ratios. **Figure 6** shows a representative load-elongation curve of each fabric sample. The vertical axis represents load per unit width and basis weight, which has the same dimension with tensile index. As found in the preliminary test, water jet processing reduced tensile strength of the web by 50 % in MD and 70 % in CD for 100 % hemp nonwoven fabrics. As the ratio of Manila hemp fibers increased, the breaking strength increased remarkably and the plateau region shortened.

Figures 7 to **10** shows tensile deformation distribution of nonwoven fabrics with the three ratios of fiber mixture. The top images of those figures show video images of nonwoven fabrics 5 or 10 seconds after the beginning of tensile elongation in either direction. The bottom images include many overlapped arrows indicating local displacement. Each image is a representative one of several runs for the same sample. As shown in Fig. 7, during a tensile deformation in MD, a nonwoven fabric composed of 100 % Manila hemp shrank in CD so that the left and right ends came together to the center because buckling occurred along a vertical line in a little right of the center. Vertical displacement is not observed with this nonwoven, as the arrows show, due to the whole shift downward. This is because a crack occurred in other parts of the sheet out of field of view of this range. Therefore, elongation does not occur evenly throughout the fabric, and breakage occurs in weak parts.

As shown by arrows in Fig. 8, during tensile deformation in CD, the nonwoven fabric from only Manila hemp, particularly in the bottom part, elongated well downward and shrank horizontally. The whole test piece happened to rotate clockwise. However, the bottom left part formed a fold, and the bottom right quarter was displaced in the down and left direction. The characteristic behavior in the case of tensile deformation in CD was even elongation over the span, judging from the result that the vertical component of the displacement vectors, that is, downward displacement increased gradually as one goes downward.

As shown by arrows in Fig. 9, during tensile deformation in MD for the nonwoven fabric composed of 75 % rayon and 25 % Manila hemp, contraction from the left and right ends toward the center was greater than those composed of only Manila hemp and the fabric did not make a dup fold. The fabric formed wavy folds at short intervals because of a lower stiffness in CD than that of the Manila hemp nonwoven. The arrow length distribution might lead to a misunderstanding that displacement is the greatest in the center, but the vertical direction component of every displacement vector has almost equal intensities. This displacement distribution diagram has fewer arrows than others because of many failed searches for the post-displacement position.

As shown by arrows in Fig. 10, during tensile deformation in CD, the nonwoven fabric composed of 25 % Manila hemp and 75 % rayon, the vertical component of the vector became larger as one goes downward. Concurrent horizontal contraction was less than that for other nonwoven fabrics of the different fiber mixture ratios. This finding implies that elongation occurs without a concurrent contraction in the perpendicular direction due to a low Poisson ratio. This characteristic property is observed with sheets with weak interfiber bonding.

Nonwoven fabrics from the intermediate mixture ratio, that is, 75 % Manila hemp and 25 % rayon, showed an intermediate tendency between the two nonwoven fabrics described so far. Note that all the data shown here is for nonwoven fabrics only and deformation of care sheets laminated with a plastic film may occur differently in practical uses.

Figure 11 shows water absorption rates of non-laminated nonwoven fabrics. The rate of the fabrics including rayon fibers was higher than that of only Manila hemp fibers. Rayon fibers tend to absorb water by swelling of themselves and the swelling velocity is relatively high. This may be a reason of the higher water absorption rate, but it can be another possible reason that addition of rayon fibers reduced interfiber bonding and increased the porosity of the fabric. **Figure 12** shows polyurethane laminate reduced the water absorption rate of the nonwoven fabrics, but did not alter its order of the fiber mixture ratio. If the swelling velocity of rayon fibers affected the rate, the fabric with a porosity reduced by the laminate would have absorbed water faster than the non-laminated fabric. Consequently, a major factor affecting the water absorption rate is considered to be porosity of nonwoven fabrics.

CONCLUSION

The best fiber mixture ratio in the trial care sheets was concluded to be 75 % Manila hemp and 25 % rayon fibers. Addition of rayon fibers at about this ratio gives the most adequate properties like soft touch and sensory smoothness to nonwoven fabrics as well as non-slipperiness against a 65/35 polyester/cotton bed sheeting. In terms of non-slipperiness, low-density polyethylene was better than polyurethane as a laminate material. The coefficient of friction of the low-density polyethylene side is higher than the nonwoven side against a bed linen cloth at any fiber mixture ratio. Addition of rayon fibers also gives relatively high water absorbency and moderate elongation under tensile force meaning shock-resistance, in spite of rather reduced tensile strength, to nonwoven fabrics.

In this work, a new method to analyze tensile deformation distribution of nonwoven fabrics using pattern-matching technique was demonstrated. From distribution of vectors indicating distance and direction of displacement determined by this method, it was found that addition of rayon fibers, during tensile deformation in MD, allows even elongation in MD, but increases contraction in CD.

For practical bedside use, the performance of the trial care sheets as they become wet needs to be evaluated. But, this will be a future area of our work.

ACKNOWRIGEMENT

This research was supported by the scientific research fund (No.12559001, B2, 2000) from Ministry of Education and Science, Japan. The authors thank Mr. Tomohito Nakayama, MS student (currently on SoftBrain Co. Ltd. Japan) for programming the image correlation software.

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Nonwoven fabric	Pulp	A. Manila hemp 25% / Rayon 75% (mixed fibers)
		B. Manila hemp 75% / Rayon 25% (mixed fibers)
		C. Manila hemp 100%
	Basis weight(g/m ²)	A . 52
		B . 66
		C . 59
Laminate	Film and adhesive	a. Polyurethane, urethane resin (15 g/m ²)
		b. Polyethylene of low density, thermal bond
	Film thickness	30 μm
	Laminate side	Side that was not contacted with Yankee dryer roll
		during drying

Table 1 Properties of care sheets and commercial water protection sheet

Commercial water protection sheet: wood pulp tissue with a polyethylene laminate



Fig.1 X-ray diffraction patterns of nonwoven fabric mounted at different angles. The web was prepared from Manila hemp fibers as a handsheet.



Fig.2 Comparison in degree of fiber orientation between nonwoven fabric and copy paper.



Fig.3 Kinetic coefficient of friction and its mean deviation between nonwoven fabric and stainless wire-wound contact object of fingerprint type.



Fig. 4 Kinetic coefficient of friction between bed linen cloth and nonwoven fabric side or film side of trial care sheets.



Fig.5 Breaking strength as load per unit width and basis weight vs. Manila hemp ratio of nonwoven fabrics with 95 % confidence intervals.



Fig.6 Load per unit width and basis weight vs. elongation for nonwoven fabrics composed of different mixture ratios of Manila hemp and rayon fibers.



Fig. 7 Video image and superimposed distribution of in-plane deformation for fabric (hemp 100 %) during tensile deformation in Machine Direction. (Time = 5 s) Each arrow is five times as long as true displacement.



Fig. 8 Video image and superimposed distribution of in-plane deformation for fabric (hemp 100 %) during tensile deformation in Cross Direction. (Time = 10 s) Each arrow is five times as long as true displacement.



Fig. 9 Video image and superimposed distribution of in-plane deformation for fabric (hemp 25% + rayon 75%) during tensile deformation in Machine Direction. (Time = 5 s) Each arrow is five times as long as true displacement.



Fig. 10 Video image and superimposed distribution of in-plane deformation for fabric (hemp 25% + rayon 75%) during tensile deformation in Cross Direction. (Time = 5 s) Each arrow is five times as long as true displacement.



Fig. 11 Water absorption rate for nonwoven fabrics made from different mixture ratios of Manila hemp and rayon fibers.



Fig. 12 Water absorption rate for care sheets (nonwoven fabrics with polyurethane laminate) made from different mixture ratios of Manila hemp and rayon fibers.