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Alternative Test Methods for Assessing Mechanical Properties of Disposable Diapers

Abstract

It is essential to examine the mechanical properties of disposable diapers that contact the skin and affect the dermatitis of babies and infants. Until now, the KES-F system has been used to determine the mechanical properties of disposable diapers. In this study, alternative methods are used to measure the mechanical properties of disposable diapers. We examined, in both dry and wet conditions, the coefficient of friction (MIU), the mean deviation of coefficient of friction (MMD), and the surface roughness (SMD) obtained from the friction tests, the compressional energy (WC), the compressional resilience (RC), and the linearity of compression curve (LC) obtained from the compression tests, the coefficient of heat transfer (K), and the maximum value of heat flux (q) obtained from the heat transfer tests, and the thickness (T) and the weight (W) obtained from the construction tests. The KES-F system has also been used for compression and friction tests for comparative reason. The contents of leakage performance were tested with wetback, absorption area, absorption capacity and retention capacity tests. After wetting, it appeared that while the MIU, MMD, SMD, and LC values increase, the RC values decrease in both the KES-F system and alternative methods. The results obtained from the KES-F system and the alternative methods demonstrate different characteristics, due to the differences in measurement techniques.

Key words: *disposable diapers, mechanical parameters, friction tests, compression tests, heat transfer tests.*

■ Introduction

Absorbent products can be broadly grouped as disposable diapers, training shorts, women's hygienic products (pads and tampons) and incontinence diapers. Although these products were perceived as luxury items in the past, their usage has increased greatly because of their easy-to-use and hygienic properties. These products affect the skin's health directly, because they are in close contact with the human skin. Even though urea is absorbed by super-absorbent polymers, the problem of wetting still cannot be totally eliminated. Wetting causes increases in the coefficient of friction accompanied with skin sensitivity. However, rashes and irritation caused by urine contact are not created by wetting alone. Other factors such as ammonia generated by the bacterial breakdown of urea, skin-skin and skin-diaper frictions, changes in skin pH, faecal protease and
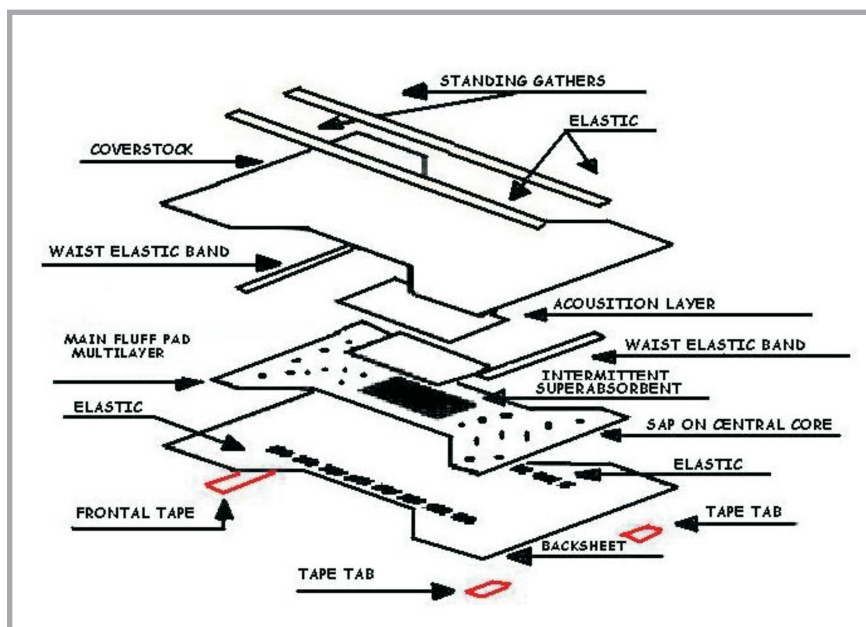
lipase enzymes activated in the pH range of 6 - 7, increases in CO_2 caused by heat and moisture and heat increase in the diaper area can also create irritations on the human skin [1 - 3].

In this research, surface, the mechanical and liquid absorption properties of commercial disposable diapers were examined to determine their performance in use. An Instron 4411 tensile tester, a U-test universal tensile tester and a Shoterm QTM-D2 were used for the friction, compression and heat transfer tests respectively. The results were compared with those obtained from the KES-F system [4 - 6].

■ Material

Five different brands of commercial disposable diapers were used in the experiments. The disposable diapers are multi-layer structures consisting of layers of different materials. The thicknesses of layers vary between 8 mm and 14 mm. The disposable diapers are comprised of a polypropylene coverstock, a coverstock back sheet, an absorbent layer consist-

Figure 1. *Sheets of a disposable diaper.*

ing of wood pulp and super-absorbent polymers, a polyethylene back sheet and elastic bands. The construction of a disposable diaper is shown in Figure 1.

A Shimadzu IR-470 infrared spectrophotometer was used to analyse the raw materials used for these diapers' sheets. The raw material can be determined by comparing the pattern and amplitude of the absorption peaks of the IR spectra with standard tables. The materials used for each sheet of samples and the weight proportion of SAP to wood pulp are listed in Table 1.

The functions of all sheets forming disposable diapers differ from one another. Liquid passes through the coverstock into absorbing sheets, but the coverstock does not let the liquid return to the upper surfaces of disposable diapers. The function of absorbing sheets is to capture the liquid itself; back sheets are required to keep it inside. The absorption sheet is the most important layer, as it affects the usage performances of the diapers. All the absorbing sheets included wood pulp and super-absorbent polymers. However, the amount and diameter of the super-absorbent polymers was different for each disposable diaper; the absorption characteristics of super absorbent polymers depend on their diameters, structure and production condition. All the super-absorbent polymers used in the disposable diapers are obtained by the polymerisation of acrylic monomers [18]. The absorption sheet is made up of wood pulp and super-absorbent polymers (in granule form) randomly distributed into wood pulp. While the wood pulps distribute the liquid homogenously, the absorbent polymers stock the liquid by converting its granule form to gel. The amount of liquid stocked depends on the webby structure

Table 1. *Sheets of disposable diapers differentiated only by the coverstock bachsheet; coverstock for all samples - polypropylene, absorption sheet; for all samples - wood pulp + SAP, back sheet; for all samples - polyethylene, waist and leg bands; for all samples - styrene butadiene rubber.*

Sample No.	Coverstock Backsheet	SAP/Wood Pulp
1	Polypropylene	0.067
2	Paper	0.031
3	Polyester	0.683
4	Polypropylene	0.250
5	n.a.	0.041

of absorbent polymers, the size, and the number of granules. The webby structure of the polymer is closely related to the polymerisation conditions.

■ Experiments

In order to determine the measurement parameters, preliminary tests were carried out for all type of test methods, and the results were analysed statistically. Then, the test conditions and numbers were decided. Measurements were taken in the laboratory conditions after the samples were conditioned for 24 hours.

Friction tests

The friction test method used in this research has been used previously for the fabrics [7 - 11]. However, we employed the same method for the first time on nonwoven and bulky structures. Preliminary tests were carried out to determine the test parameters for these sorts of materials. The Instron 4411 tensile tester was slightly modified for the friction tests. A test device with a 15 cm × 52 cm horizontal stainless steel plate, a nonfrictional pulley, a sled and both ends hooked with fish line was added. [8, 11] A simple diagram of this arrangement is shown in Figure 2. The sample was located on the plate attached onto the lower jaw of tester, and the sled on the sample was pulled via a pulley and fish line connected to the tester's movable upper jaw.

After preliminary tests, the surface material, the dimensions, the weight, and the speed of the sled and measurement distance were selected for the actual tests with a leather 3 cm×3 cm sled, weighing 105 g, at a speed of 10 mm/m over 80 mm distance. The friction tests were performed on an 8 cm×12 cm marked area in the centre of the samples, which were conditioned for 24 hours. In order to prepare the wet samples, the marked area of each sample was moistened with 36.6 ml of 0,9% NaCl solution and left for five minutes. Four dry and four wet samples from each brand were tested for friction properties.

Because the bulky structures have uneven surface properties, only the coverstocks of disposable diapers were assessed with the same test parameters for the roughness. The required force for maximum transposition in the tester was taken as the roughness value. In order to obtain the roughness values, nine samples in

both dry and wet conditions were tested from five brands.

Compression and fabric thickness

The compression tests were carried out in a U-test universal tensile tester. It was also necessary to determine the test parameters for the bulky materials. A 20 mm-diameter stainless steel compression cylinder was screwed on the load-cell positioned on the ceiling of the tester frame, and a 50 mm-diameter stainless-steel floor plate was attached to the movable upper jaw. The sample is positioned on the floor plate and compressed between these two planar surfaces. A simple diagram of this setting is shown in Figure 3.

A 5-kg load-cell was used in the experiments; the accuracy adjustment of the tester was 0.5 g. The fabric thickness and compression results were collected via load and elongation graphs. After preliminary tests, the parameters were selected as 12 mm/s speed and 1.47 N maximum force compression tests. 50-mm diameter pieces from the crotch region of the diapers were used as samples, and were conditioned for 24 hours. In order to prepare the wet samples, a 50-mm diameter area of the diapers was moistened with 7.5 ml of 0.9% NaCl solution and left for five minutes. Fourteen dry and fourteen wet
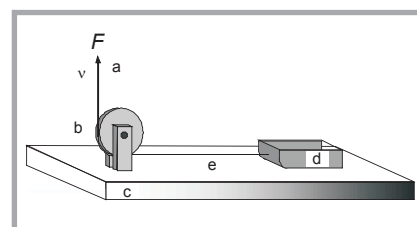

Figure 2. *Friction test apparatus: a - upper jaw connection, b - non-frictional pulley, c - stainless steel plate, d - sled, e - fish line.*
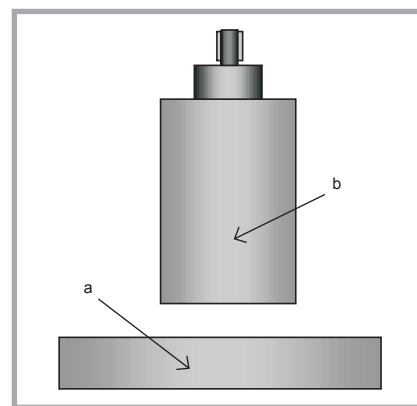

Figure 3. *Compression test apparatus: a - floor plate, b - compression cylinder.*

samples from each brand were tested for compression properties.

Heat transfer tests

The thermal conductivity of the samples was measured using a Shoterm QTM-D2 thermal conductivity meter working with a modified 'Hot Wire' method of standard DIN-51046 [12]. The tester was used to discover the coefficients of heat transfer (K) and the maximum values of heat flux (q). This method has been used for textile materials for the first time because the method requires a certain thickness, which conventional fabrics do not have. A wire is embedded in the material being investigated, and is then heated with a constant electrical source. The thermal conductivity is determined by evaluating the temperature rise in the hot wire, which depends on the thermal conductivity of the sample surrounding it. Pieces measuring 9.5 cm × 4 cm were cut from the crotch region of the diapers and conditioned for 24 hours. 2.16 kPa pressure was applied on the samples for the heat transfer tests. The wet samples were damped with 14.5 ml of 0.9% NaCl solution, and covered with polyethylene film to prevent the tester from any damage. Covering the samples with film did not have any significant difference on the heat transfer coefficients. Four dry and four wet samples from each brand were tested for thermal conductivity properties.

Leakage performance

Wetback, absorption area, absorption capacity and retention capacity tests were performed to clarify the leakage performance for the five brands of diapers. All the samples were conditioned for 24 hours before the tests. Test ENG/T8/4-2 was used [13, 14]; this method involves running 25 ml of 1% NaCl solution into the crotch region of a diaper and, as soon as the fluid has been absorbed, applying a disc of filter paper (110 mm diameter) with a mass on top for one minute. The weight is rectangular (115 mm × 60 mm) with a mass of 1.05 kg (pressure = 1.49 kPa). The weight of fluid absorbed by the filter paper was recorded as the wetback weight. The absorption area test consisted of measuring the maximum width and maximum length of the wet area of the diaper on completion of the wetback test, and recording the product of these two as an estimate of the absorption area [15 - 17]. The tests were repeated eight times.

The absorption capacity and retention capacity measurements were performed using the TEFO disc method on 80-mm diameter discs of diaper cut from the crotch region [13], which were compressed under a pressure of 100 Pa and 150 ml of 0.9% NaCl solution applied at 7 ml/s via a hole in the centre of the compression weight. After a delay of ten minutes, the weight of fluid retained by the sample is calculated by subtracting the weight of fluid not absorbed from the weight of the original 150 ml, and recording the result as the absorption capacity. Next, an additional weight is applied to the disc, giving a pressure of 3 kPa, and after a further delay of five minutes, the weight of fluid retained by the sample is calculated and recorded as the retention capacity. The absorption capacity and retention capacity measurements were repeated four times.

■ Results and discussion

The mechanical properties and leakage performances of five different brands of diapers in dry and wet conditions are summarised in Table 2. In order to find out the difference between the KES and our methods, paired sample t tests and linear regression analyses, both of which were at least at 5% significance levels, were applied to the friction and compression values summarised in Table 3.

Friction test results

The diapers' surface property values rose markedly after wetting. Irregular placement of absorbents causes unequal liquid absorption through the surface and leads to unevenness. Along with the wetness, this may be the reason for the increases in the coefficient of friction (MIU), the mean deviation of MIU (MMD) and the roughness (SMD) values of the wetted diapers. Figure 4 illustrates the KES and our method's MIU results for wet and dry variants of five commercial diapers. The MIU values of our method are about half of those for the KES in both dry and wet conditions. The wet and dry MMD values of KES and our methods are demonstrated in Figure 5. Although no relationship could be established among the wet values, the dry MMD values of our method are about half of those of KES.

This is the expected result, due to the usage of different instruments. The KES-F system uses a piano wire, while a friction plate is used in the present method.

A wire can penetrate into the bulky structures and measures the frictional forces of acting on the surface, along with the additional pushing forces to the sides. Because a plate can only record the frictional forces, the results obtained from our method are lower.

The roughness values (SMD) of our method and those of KES are not comparable. In the KES system, roughness is the distance between the highest and lowest points on the surface. However, we measured the smallest force necessary to overcome the highest point of the surface. Wetting increased the roughness very greatly because the unequally swollen absorbents cause uneven surface properties.

Compression results

When the samples are wetted, the distance moved during compression increased along with the compressional energy (WC) and the linearity of the compression curve (LC) due to the swollen absorbents. However, the compressional resilience (RC) decreased, because of the lower forces of higher viscosity of swollen absorbents. Figures 6 - 8 show the changes in WC, RC and LC values due to the wetting.

Figure 6 shows that while the WC values of the KES decrease with wetness, our WC values increase. There is no relationship among the wet WC results, but the WC-DRY-OUR values are about four times higher than the WC-DRY-KES values. The reason of this is that the maximum compression force used in our experiments is about seven times higher than that in the KES. Another reason for these differences may be that the swollen absorbents are slid to the sides when the ball-shaped component is pushed, in the KES method.

The RC values decrease with wetness in both the KES and our methods. There is no relationship among the wet RC results, but the RC-DRY-OUR values are about 1.2 times higher than the RC-DRY-KES values. The LC values increase with wetness both in the KES method and ours. The LC values of our method are about 10% less than those of the KES both in dry and wet conditions. The KES system uses a rubber ball for compression tests. The KES results are subject to influence by the elasticity of the rubber ball as well as by compression [4 - 6].

Heat transfer test results

When the diapers were wetted, the coefficient of heat transfer (K) and the heat flux (q) values increased considerably, as can be seen from Table 2. The percentage changes due to the wetting reach 584% and 737% in heat transfer (K) and the heat flux (q) values respectively. The increase of the q and K values result in less warmth.

Leakage performance tests results

Table 2 shows that the samples have diverse liquid absorption properties irrespective of their dry weights. It can also be observed that the increase in the weights of wet diapers is in proportion with the retention capacity. The thickness of the dry and wet diapers displayed an alteration range between 2.39 mm and 3.83 mm. The sample with the minimum thickness alteration also displayed the best fluid retention capacity. Actually, the retention capacity is proportional to the weight increase and disproportional to the thickness increase. This suggests

Figure 4. Coefficient of friction (MIU) values of 5 wet and dry commercial diapers obtained from KES and our methods.
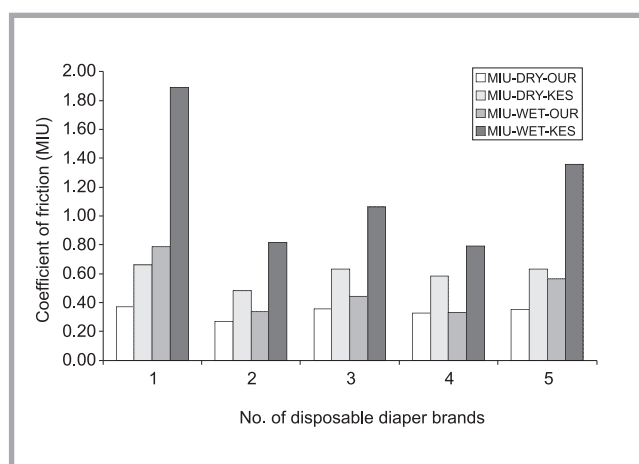
that the amount and size of absorbents used has a considerable influence on the amount of thickness increase.

◼ Conclusions

Although KES-F was used to determine the mechanical properties of disposable diapers, there is no standard objective method for measuring the mechanical

properties of bulky structures such as disposable diapers. The main objective of this research was to elaborate methods with optimum working conditions to determine the mechanical parameters of bulky structures. The current research has revealed that the alternative methods with selected test parameters can be used instead of the KES-F system to determine the surface and compression

Table 2. Mechanical properties and leakage performances of the dry and wet diapers; denotations: MIU - coefficient of friction, MMD - mean deviation of MIU, SMD - roughness, WC - compressional energy, RC - compressional resilience, LC - compression curve, K - coefficients of heat transfer, q - heat flux, T - thickness, W - area mass.

Properties	DRY					WET				
Sample No.	1	2	3	4	5	1	2	3	4	5
MIU	0.3723	0.2721	0.3564	0.3279	0.3550	0.7862	0.3397	0.4437	0.3308	0.5652
MMD	0.0277	0.0097	0.0199	0.0271	0.0287	0.2272	0.0199	0.0918	0.0238	0.0257
SMD, N	0.0021	0.0043	0.0032	0.0042	0.0076	0.3673	0.2463	0.2463	0.2075	0.4786
WC, J/m^2	0.6732	0.5924	0.6939	0.7184	0.6930	0.7216	0.7041	0.6346	0.7562	0.7432
RC, %	53.12	58.77	51.17	51.23	55.27	51.27	39.01	47.29	43.96	58.13
LC	0.0579	0.0545	0.0552	0.0607	0.0592	0.0853	0.0780	0.0748	0.0981	0.0854
K, W/mK	0.0549	0.0555	0.0537	0.0666	0.0504	0.2613	0.3608	0.1577	0.1925	0.2556
q, W/m^{2}K	47	57	46	54	40	201.9	477.1	191.1	199.1	273.6
T, mm	12.18	10.74	12.66	12.24	13.65	15.53	13.59	15.06	15.29	17.49
W, g/m^2	923.97	788.86	1333.8	1005.1	889.20	1198.6	1105.1	2453.3	1679.1	1025.4
Wetback, g	-	-	-	-	-	0.6762	0.7293	0.6951	0.7079	0.6997
Abs. area, mm^2	-	-	-	-	-	20.92	36.25	31.63	25.71	19.02
Retention capacity, g	-	-	-	-	-	67.41	67.35	135.16	93.04	58.31
Absorption capacity, ml	-	-	-	-	-	81.50	75.83	135.83	97.33	81.67

Table 3. Results of Statistical Analyses; Note: significant at least at the 5% level (except MMD-Wet); denotations as in Table 2.*

| Properties	Paired t-tests results				Regression Analyses Results			
	Mean		Paired t-ratio*	Probability	Correlation Coefficients	Linear Regressions	F-ratio*	Probability
	Our	KES						
MIU-Dry	0.3368	0.5998	-18.953	0.000	1.000	Our=0.001+0.56KES	88332.97	0.000
MIU-Wet	0.4931	1.1833	-5.815	0.004	1.000	Our=0.416KES	2359550.34	0.000
MMD-Dry	0.0226	0.0429	-4.844	0.008	0.898	Our=0.003+0.454KES	12.42	0.039
MMD-Wet	0.0777	0.0525	0.753	0.494	0.726	n.a	n.a	n.a
WC-Dry	0.6742	0.1686	31.136	0.000	1.000	Our=0.001+3.995KES	308482.05	0.000
WC-Wet	0.7119	0.1046	28.746	0.000	0.130	n.a	n.a	n.a
RC-Dry	53.91	45.87	35.160	0.000	1.000	Our=-0.662+1.19KES	16519.77	0.000
RC-Wet	47.93	36.57	3.254	0.031	-0.153	n.a	n.a	n.a
LC-Dry	0.0575	0.6903	-51.156	0.000	0.999	Our=-0.002+0.087KES	1503.81	0.000
LC-Wet	0.0843	0.8634	-25.757	0.000	0.924	Our=-0.1+0.109KES	17.59	0.025
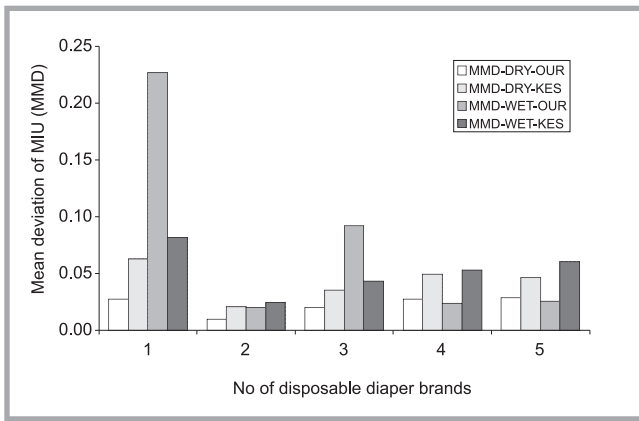
Figure 5. *Mean deviations of MIU (MMD) values of 5 wet and dry commercial diapers obtained from KES and our methods.*

Figure 6. *Compressional energy (WC) values of 5 wet and dry commercial diapers obtained from KES and our methods.*
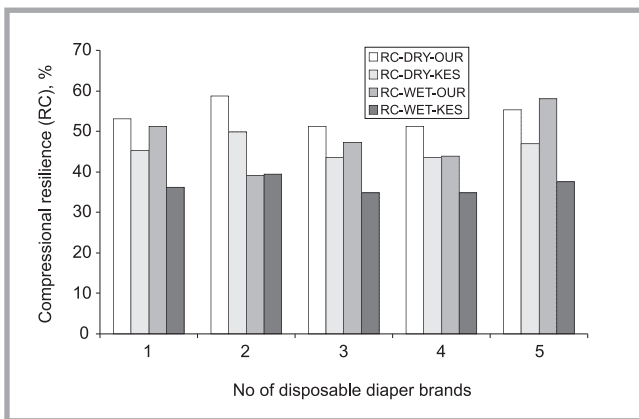

Figure 7. *Compressional resilience (RC) values of 5 wet and dry commercial diapers obtained from KES and our methods.*
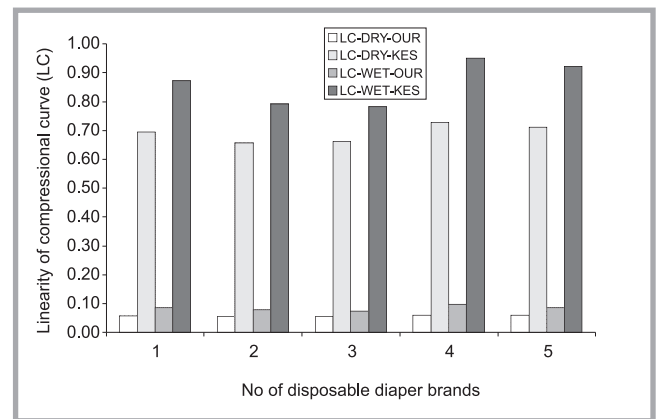

Figure 8. *Linearity of compressional curve(LC) values of 5 wet and dry commercial diapers obtained from KES and our methods.*

properties of bulky structures, especially in dry conditions.

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