LABORATORY AGEING TEST DEVICE FOR PRESS-FELT CLOTHES OF PAPER MACHINE

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Abstract:

The main part of the de-watering process in a paper machine (PM) is carried out by means of mechanical pressing, which considerably influences the paper quality and energy efficiency of the paper machine. This paper discusses a method for controlled press-felt mechanical degradation. For our research, a special test device was designed and developed to simulate press-felt ageing in the pressing section of paper machines. All the described methods and tests were carried out in the Institute of Fibre Materials Science at Tampere University of Technology.

Key words:

Test device, paper machine clothing, fibres, mechanical degradation, press-felt

Introduction

Paper making has always had a remarkable effect on the market economy. The productivity and speed of paper machines has developed rapidly during the last few decades. This puts great demands on each step of the production line and emphasises the need for new innovations.

Paper machine clothes (PMC) are used in the forming, pressing and drying stages. In each of these stages, there are several positions where special technical clothes are used. These clothes are customised for every paper machine. The raw materials of the clothes should withstand the manufacturing process and harsh conditions in the paper machine. Throughout the entire operation cycle the properties of the materials should remain as good as possible [1, 13].

In paper making, the pulp slurry is pumped onto the forming section and transferred as a sheet to the pressing section. During this process the mixture of water and fibre changes from 99:1 to 60:40 from the beginning of forming to the end of pressing. So, the most important duties of the clothes are to de-water as much as possible, to transfer and support the sheet [1].

At the pressing section the efficiency of water removal capacity depends on the nip and the felt. The nip is the gap between two rolls which can be one or twice (see Figure 1). Typically there are three or four nips in the paper machines. After passing the nip, one special aspect of the felt is how it inhibits re-wetting. This can be controlled by the construction of the felt [12].

After wet pressing the sheet goes to the drying section, where the mixture ratio is 5% (water) and 95% (fibre) at the end of the drying process [1].

So, the felts have great influence on the produced paper quality as well as the energy requirement [12]. For example if the sheet dryness increases by 1% in the press section, then the drying energy load decreases by 3-4%. This means a considerable saving in overall energy consumption [5].

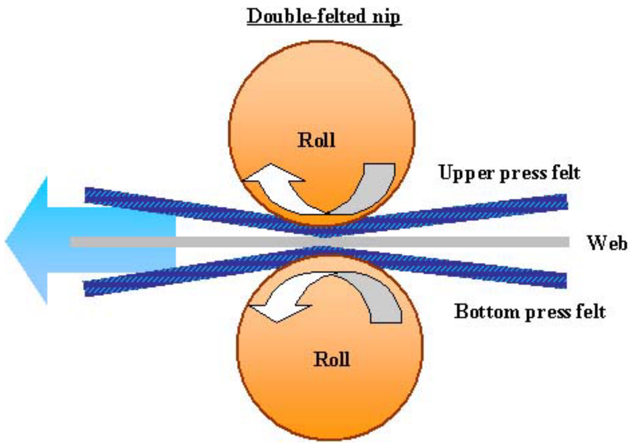

Figure 1. This nip builds up about two rolls and two press felts. Between them the water is removed from paper web

Because of the ultimate demand for efficiency on paper making, the development of fibre material is actively heading for new goals. The Institute of Fibre Materials Science at Tampere University of Technology offers possibilities for experimental and theoretical research. The Institute provides know-how and environment for PMC-tests.

Background

Material development can be accelerated by bench-scale testing of products which are under mechanical stress in conditions simulating the operation of a paper machine. Comparison testing in controlled surroundings helps to test new and developed fibre materials more precisely. Small-scale trials compared to pilot paper machine tests underlie and accelerate this development.

The raw materials of the PMC have been tested in various ways on laboratory scale. The raw materials, such as staple fibres and monofilament yarns, have been exposed to different mechanical stresses. Different test standard methods, such as the Stoll and Martindale abrasion tests, have been used to wear down raw materials. After testing, they have been microscopically inspected. The problem with these ordinary textile tests is that they do not simulate the real conditions at the paper machine. In the pressing nip there is always high pressure, tension with friction and the impact of paper chemicals, but in the ordinary tests there are not so many of these factors present simultaneously. A test device, the so-called PMC-device, has been developed in the Institute of Fibre Materials Science to simulate the operation of a paper machine. The idea of the PMC testing in bench-scale was first introduced at the 4th World Congress of Polyamide 2003. It is possible to achieve more helpful results without large investments of time and money by using this device [7].

Computers and their programs are sufficiently well developed that they can be used to simplify the nip pressure by simulations. These simulations help to develop new structures for the felts, and can virtually pre-test their de-watering capacity before the preparation of a felt [4]. This therefore enables the cutting of alternatives before mechanical tests, although it does not eliminate the need for practical tests. Practical testing in the simulated paper machine environment is required for the observation of mechanical degradation. This information is valuable for the production of industrial felts.

Circumstances in paper machine

The production speed of high-speed paper machines of today can reach up to 2000 m/min, and in the very near future the machines should be able to achieve 2500 m/min or even 3000 m/min speeds. Using high speeds, the felts pass through the nip several million times during their life. The nip pressure can be over 10 Mpa, the width of the felt can be over 10 m and the length can vary from 10 m to 60 m [2, 3]. In paper machines, the average lifetime of the felts is about 30-90 days [1]. So the felts and their materials undergo demanding circumstances for quite a long time.

The effectiveness of the press depends on the nip impulse, which is the main wear factor of the felt. The paper type and production efficiency are the reasons for different types of nip in the pressing sector. The nip types are separated by nip length. Ordinary nips are a few centimetres long, whereas the shoe presses can be several decimetres long. In addition to the nip, an accumulation of filler increases the erosion of the felt [1].

Research project

One part of the larger project was the building of the test device and its development. The main focus of the research is the mechanical stress on the different types of the staple fibres. The resilience of the fibres was studied using these ageing tests.

The test results of the whole project have not been included in the article, which was written after several ageing tests.

Experimental

After specification of the test conditions, the process of engineering the equipment began, which included defining the size of the device, choosing the materials and preparing technical drawings. During the planning it was stressed that the device should be safe for use in wet conditions, and that all possible electric shock should be totally eliminated. Furthermore it was decided to make the device and its controllers as user-friendly as possible. At the same time, the proper location for the heavy device was chosen.

PMC-device

Technical construction

The important issue for device planning was to select proper materials, since speed, mechanical stress and pressure during the testing would be demanding. The PMC-device was built of strong stainless steel to make it stable. The weighty material made the device heavy, while nevertheless meeting the demands. The steel material protected the parts of the test device from water and solution, and this helped to keep the device clean.

The PMC-device (see Figure 2) is based on two parts, the body and the stand of the device (not shown in figure). Between two parts is a fluid receiver, which is horizontal. It collects water or solution, as the used liquid is squeezed from the nip, and part of it flows down the body of the device.

Other essential parts of the device are fastening pins, a pipe, a guide roll, screwing bars, two extra rolls, two cambered operating rolls, a push button for emergency stoppage, and technical operators.

The fastening pins hold a guide roll-up when the felt sample is put on rotating rolls. The pipe can be used for water or solution spray. The pipe and nip are near each other. An upper and bottom roll belongs to the nip. Below the bottom roll is a small collection sink where the solution flows. The screwing bars are for controlling and tightening the guide roll, which guides the position of the sample in the run. Two extra rolls give more mechanical stress and increase the contact surface with the sample. The cambered rolls rotate the sample, and they have the biggest contact area with the sample. The technical operators observe the movement of the sample, and ensure that it does not drop out on the rolls.

The larger components of the device are explained in detail in the next section of this work.

Filler and its feed

The decision to use the filler supported the idea to simulate the pressing section of the paper machine as accurately as possible. The use of water without filler would lead to the compaction of the felt sample without abrasion of the staple fibres.

The filler consists mainly of $CaCO_3$, but HCl and $MgCO_3$ are found in it in small amounts. The percentage of grain size below 1 µm is 29% and below 2 µm is 53%. The pH is about 9, its the specific gravity is 1.7 kg/dm^3 and the dry solids content is 65% [6]. The filler and water were mixed together to a specific ratio.

The existence of the solution inside the sample during the entire ageing test was confirmed by using a circulating pump. The solution was pumped back from a container to the surface of the felt sample, when it had flowed down to the container. More solution was added in small amounts to the container during the testing, since it evaporated slowly.

The circulating system consists of a solution pipe, the solution container, the circulating pump and pipes between parts.

Washing head

The solution was meant to wash away from the test sample, since the clean sample was easier to test and analyse in the laboratory. Secondly, this kind of PMC maintenance work is done in the paper mills, since the washing extends the lifetime of the clothes. Based on these aspects, we decided to build a washing head.

The washing head was built up on a vacuum box with ceramic bars, a water pipe, a vacuum unit and pipes between parts.

Heating

The temperature in the paper machine is higher than room temperature. There was thus a need to build a heating system for the PMC-device.

The heat was controlled with a separated system, which consisted of infrared (IR) lamps for heating, plastic covers for gathering the heat, a digital thermometer for temperature control and a water bath for pre-heating the solution in the container.

Control panel

Test parameters were set by the control panel, which consisted of a device controller and a IR-controller. The rotation speed, amount of rotation, nip pressure and movement of the upper roll of the nip (up/down) could be set by the device controller. Naturally the device shutting and starting could also be done by the controller.

The switch for two lamps (number 1 or 2), time frame and the temperature used was set by the IR-controller.

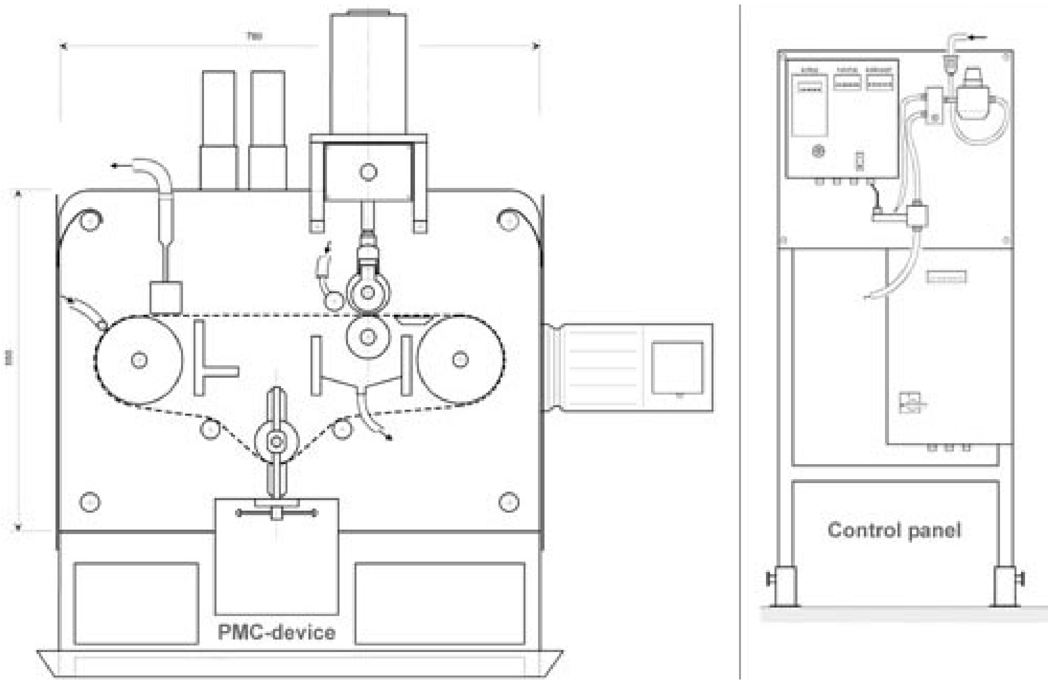

Figure 2. The principal picture of the test device is on the left. The dashed line represents the endless felt sample in the machine direction. The control panel for the device and the IR-controller are on the right

Technical data

The rotation movement in the PMC-device is created by a chain and has a speed range up to 160 m/min. The chain connects an electric motor and the operating roll. The whole device should fit into a small area, whose width is 850 mm, height 1570 mm and length 870 mm. The measurements of the body are smaller: the width of the device is 375 mm, the height 780 mm and the length 550 mm. The width for all rolls is 300 mm.

The control panel, the heating system, the solution circulating system and the washing head are all adjustable.

Test samples

At the same time as the device was built, the felt samples for test runs were planned and prepared. The samples were prepared following the manufacturing process in the PMC. The preparation was multi-phased.

The most common method of manufacturing the press felt is to produce it from woven fabric (yarns), which forms a base fabric, and batt layers (staple fibres). The preparation of the batt layer includes blending, carding and pre-needling processes, and preparing the base fabric includes warping, weaving, burling and finishing. The batt layers and the base fabric are combined by needling. After needling the product is finished, checked and shipped to the customer [1].

So the base fabric can be woven but also sometimes non-crimped. The raw materials of yarns are mostly synthetics, primarily polyamide polymers. The use of synthetic polymers greatly improved the properties of the base fabric compared to the materials used before. Their resistance characteristics to the press load improved notably. The effect on the efficiency and the whole felt was significant, since the running property became better and the lifetime increased [1, 4].
The yarns which the press felts are made of can be different types: monofilaments, plied multifilaments, cabled monofilaments or spun yarns. The use of different yarn types broadens the possibilities of achieving different operational characteristics of the press felt [1]. It should be remembered that the felts are usually tailor-made for each position of the PM stages.

The raw material of the batt layers is also filament, but these are cut. Their length is shorter and their diameter is a great deal smaller. With different finenesses of the staple fibre, more exact properties can be achieved for the press felt and its end use [1]. The surface smoothness or roughness of the felt is the most important property, and it can be affected by the quality of the batt.

During the felt manufacturing, the most physically demanding stages for the raw materials are carding, pre-needling and needling, which can cause mechanical damage. For example, during the needling the materials pass through needle plates 20 times or more, and each time the barbed needles penetrate the batt layers and the base fabric. Several needling times are needed for better surface quality, better dimension stability of the felt, and to improve the clothes' ability to withstand bigger loads and increased speeds [1, 11].

For the test run, a simple construction of the press felt was prepared, since the staple fibre was the main focus of observation. The PMC-device was planned for samples, whose maximum width was 240 mm and maximum length was 1500 mm. Due to the dimensions of the felt sample, the woven fabric was made on a narrow loom. The felt sample was also endless like a loop (see the dashed line in Figure 2). The sample consisted of the staple fibre layers on both sides of the woven fabric. The raw material of the staple fibres and yarns was polyamide 6 (PA 6).

Testing

Test plan

The aim of the first test run was to evaluate the device performance, as had been planned. Another aim was to see clearly the effects of the mechanical stresses on the sample. Before testing, the prepared samples had been stored for 24 hours in a room with standard humidity conditions.

The pre-test run was planned and the parameters were decided on the basis of a real process in a paper machine. At the beginning, the rotation the velocity was 40 m/min and the nip pressure was 150 kp (1.47 kN). The number of rotation cycles was set at 2,000 cycles.

Pre-test run

The endless sample was not easy to put on the device and it had to be wetted with water. After the felt sample was assembled on the test device and the test parameters were set, the pre-test was started.

After a few cycles the water pipe was opened and then the upper roll of the nip was dropped down. The wet sample under pressure began to stretch after 200 cycles. The stretching caused the felt sample to wind from one end of the operating roll to the other. The guide roll was tightened downwards to stop this unwanted movement. The tightening continued until the stretching ceased and its rotation direction remained straight.

This setting time simulated a start-up in a paper machine. After the start-up, the speed and the nip pressure were increased. The results of the pre-test run were that the optimum values wereobtained: the rotation speed was 90 m/min and the nip pressure 255 kp (2.50 kN). The important criterion was that the sample did not wrinkle before the nip with these values.

Ageing test

After assembly, the watering was started and the tightness was set. These ensured that the felt sample stayed straight on the rolls. During the watering, the solution was made and the heating system without the IR-lamps was activated. After a few hundred cycles the water flow was stopped, the nip was taken up and the rotation was stopped.

The ageing with the solution was started next. Firstly, the pipes between the solution system and the device were put in the right places. The circulating pump was put on, the device began to rotate again and the nip was closed. The sample rotated for eight hours, which meant about 20,000 cycles. At the end of the ageing, a small piece was taken from the edge of the sample for the laboratory test and then the sample washing began. The water from the sample was sucked to the vacuum unit, which was connected to the vacuum box by a pipe. The vacuum unit had to empty during washing. The colour of the sucked water as revealed when the felt sample was clean. It took about one hour (2000 cycles) to get the sample clean. After washing, a small piece was again cut from the edge. The felt sample was left on the PMC-device over night.

On the next day, the ageing test was carried-out in the same way as the first day: first the watering, then the solution run and lastly the washing run. The pieces of the felt sample for the laboratory tests were also taken after every day. Throughout the week (5 days) the test run was executed same way. During one week the sample underwent 100,000 nip cycles and 10,000 washing cycles.

Test using higher temperature

As previously mentioned, the PMC-device is equipped with IR-lamps, which are very convenient to use in limited place. The heating test was done separately in order to ensure that the base elements of the device worked correctly. Special glass plates protected the IR-lamps from the splashing of the solution.

The test was carried out only on the dry felt sample without the nip pressure. The device was put on, the run parameters were set, the device began to rotate the sample and the nip was closed. When the device reached 90 m/min, both IR-lamps were switched on. At the beginning the temperature was set to +40°C. After reaching this temperature it was increased in steps. The heat rising was controlled by the sensors of a digital thermometer (two channels). One sensor was located above the surface of the sample, and the other followed the solution heating inside the container. The target temperature on the surface was over +70°C, which was easily reached.

One more significant aspect arose during the heating test; when the temperature rose, the stretching of the sample increased. The adjustment tolerance for the stretching was not enough at very high temperatures (over +80°C), and so the tightening movement of the guide roll should be larger if the use of higher temperatures is required.

In practice, the heating volume was so powerful from the IR-lamps that the sample had to rotate all the time. If the felt sample stopped during the heating, it could have caused damage to the felt sample or even melt it into two pieces.

Results

The operation of the PMC-device and observations of the felt samples have been considered separately.

Test device

The length of the nip is dependent upon the material of the rolls and their diameter. The nip in the PMC-device simulated the ordinary pressing nip, where the rolls are hard steel. When the device has small diameter rollers, it leads to a short and sharp nip. Equipment engineering and testing limitations compared to the industrial process (higher speed and linear load) are accepted in the laboratory scale. The size of the samples was kept as small as possible and the preparation time to reasonable limits, since they influence costs. Moreover, the intention was to preserve as much unaffected material for testing as possible. All the factors that influence cost-effectiveness have been taken into account in the research.

The PMC-device worked as planned after modification. After promising results and a few improvements the testing was continued. After several ageing tests, the optimal parameters for the PMC-device were established as follows:

- speed 90 m/min;
- pressure 255 kp, which corresponded to linear load 8.34 kN/m;
- maximum length of the nip 2.0 mm;
- nip time 1.33 ms.

The speed and the pressure were connected to each other. If the speed or the pressure was raised, then the runnability of the sample became complicated (sample wrinkling).

Here we compare the process parameters between the PMC-device and a PM. The calculations are based on the following assumptions: the length of the felt is 30 m, the speed is 1800 m/min and the length of nip is 30-40 mm in the PM. Based on these assumptions, both apparatuses have the same nip time, and therefore the number of cycles per minute is 60. The pressure in the nip varies from 2 MPa to 4 MPa in the paper making, whereas in the PMC-device it is 4.17 MPa. So the pressure in the nip of the PMC-device is high. This helps to accelerate the fibre degradation in the felt samples.

Felt samples

The effect of the mechanical stresses could be observed on the small pieces of the samples. With the Scanning Electron Microscope (SEM) the compaction of the felt samples and the damage to the surfaces could be observed, as seen in Figures 3 and 4. Moreover the staple fibres are deformed from a circular shape to a flat one. The surface and edges of the flat staple fibres were worn.

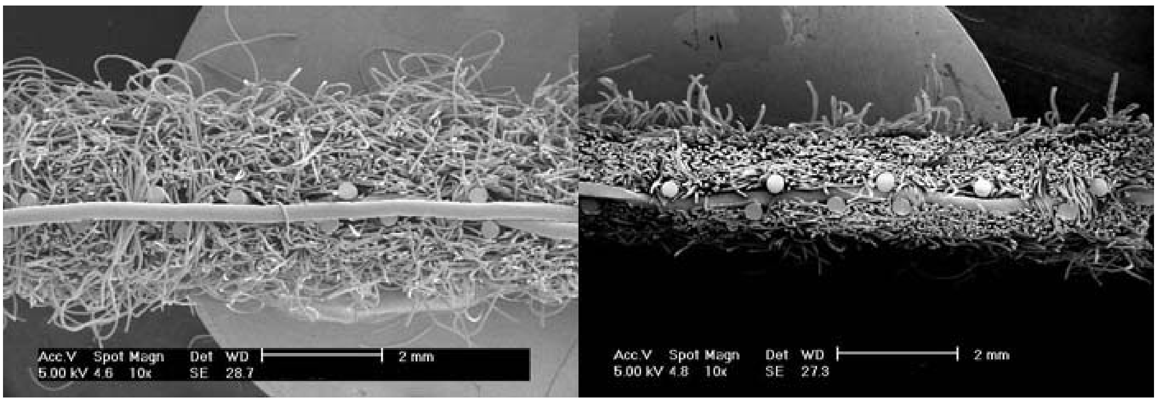

Figure 3. Untested sample (on the left) and tested sample (on the right)

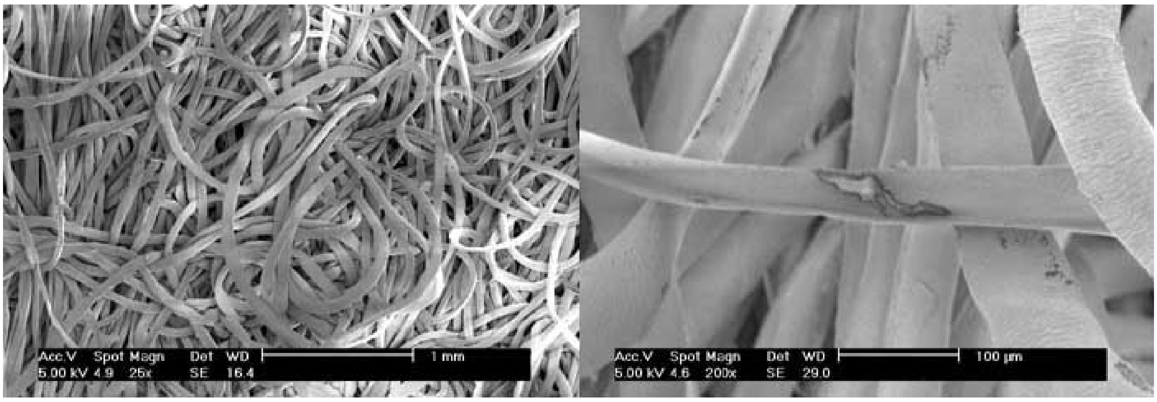

Figure 4. Surface of tested sample (on the left) and some flat staple fibres (on the right) on the paper side of the felt

The SEM pictures are taken from the paper side of the felt sample. The same kind of effects of mechanical degradation can also be observed on the roll side.

The curves in Figure 5 reveal how the properties of the felt sample and their material decrease during the ageing. Usually some of them collapse significantly during the first 100,000 cycles. The drawn lines start from the value of new sample and end at 300,000 cycles. The trend lines indicate thickness, mass per area and air permeability in a certain number of cycles (100,000, 200,000 and 300,000). The difference between curves of the mass per area and the thickness is explained by the use of the filler. As early as the first testing day this damage could be seen, and it increased after every testing day.

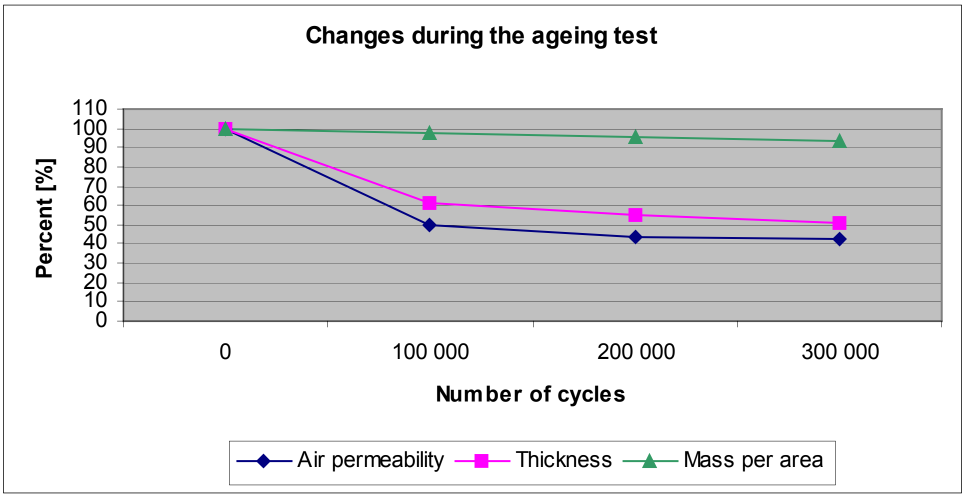

Figure 5. Changes in properties of the felt sample during the ageing test

The main effect of testing was the compaction of the samples and the loss of ability to recover from pressing. This could also be observed from the cross-sectional shape of the fibres, which was deformed from circular to flat. The mechanical degradation could best be observed on the surfaces of the felts. There was much fibre breakage, flat and worn fibres. These indicate wear of the fibre, fibre loss and degradation of the felt structure.

More detailed conclusions of the connection between the mechanical stress and different staple fibre types are not dealt with in this article.

Conclusions

The primary observation was the effects and their types on the felt samples and used staple fibres which the PMC-device had generated under the created conditions.

The PMC-device suited its basic duty even through it needed some improvements. It also revealed great potential for expanding the range of its testing services. The device very well simulated the circumstances at the pressing nip in the paper machine, and some numerical correspondences were found to the industrial process.

The nip time and the nip strike amount per minute are important factors in papermaking and the loss of wear-resistance in the clothes. The use of the filler also has a remarkable effect on abrasion with mechanical stress, since the use of pure water causes only compaction. The whole impact is so enormous from the point of view of the clothes that it changes all the properties of the felts during the running time.

The felt samples were good indicators to check whether the parameters of the ageing test and the PMC-device were correct. After several tests, the effect of the mechanical stress on the various felt samples could be seen. The decreasing of properties (thickness, etc.) and the setting time of the felt in the PMC-device corresponded quite well with the chain of events in a real-life situation.

In the PMC the air permeability difference between new and used felts is remarkable. The decreasing of the permeability is 40-60% [13]. This is the same level as that of the research (see Figure 5). Naturally the structure of the felts and other manufacturing aspects are not the same, but it proves that the received results are not far from real life, when the mechanical wear of the fibre and the felt structure are considered.

So, it is possible to conduct reliable testing for raw material suppliers with the PMC-device, since it is a cost-effective and rapid way to test the materials on a laboratory scale under paper machine conditions.

Further action

The prototype performed and demonstrated the harsh conditions in the paper machine very well, but the device can be improved in details. The need for development is natural, when a new device is built and more experience of its use has been achieved. These improvements aim at the ease of use of the PMC-device. The device will be prevented from failing by maintenance in the form of regular device washes and inspections.

Many possibilities exist for a broad range of measurement services from the PMC-device with minimum modification. These could include researching different surface materials for rolls, effects on seamed felts or fabrics, the use of various fillers during the ageing test, etc. The expansion will serve a larger region of the paper textiles.
For example, the ability to observe the interaction between the roll and the press felt is an important aspect, since the new surfaces of the roll are developed to improve the quality of papers, and at the same time to increase the life cycle of clothes [10].

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References:

1. *Adanur, S., Paper Machine Clothing, Asten, 1997.*
2. *Albrecht, W., Fuchs, H., Kittelmann, W., Nonwoven Fabrics, Wiley-VCH, 2003.*
3. *Atkins, J., A beginner's guide to towel and tissue, part 1, TAPPI, SOLUTIONS! For people, Processes and Paper, 2004, September, Vol. 87/No. 9, 32-36.*
4. *Best, W., Molls, C., Weiss, M., Development of future oriented clothing through press nip simulation, Paper and Timber, 2004, Vol. 86/No. 4, 264-266.*
5. *Bottiglieri, J., Machine Clothing strategies keep wraps on cost, TAPPI, SOLUTIONS! For people, Processes and Paper, 2004, August, Vol. 87/No. 8, 26-30.*
6. *Data sheet, Detail specification of Hydrocarb Filler, Omya Oy, 15.05.2005.*

7. *Harlin, A., Paper Machine Clothing Performance Evaluation in Bench-Scale, 4th Annual World Congress, Zürich, 2003.*
8. *Kinnunen, L., Uusi järjestelmä mittaa formation online, Paper and Timber, 2004, Vol. 86/No. 2, 86-88.*
9. *Kurki, M., Kekko, P., Kouko, J., Saari, T., Laboratory scale measurement procedure of paper machine wet web runnability. Part 1., Paper and Timber, 2004, Vol. 86/No. 4, 256-262.*
10. *Partanen, J., Puristinosan käytettävyys tehostuu uudella pinnoitteella, Paper and Timber, 2004, Vol. 86/No. 3, 148-150.*
11. *Strössner, J., Wizemann, G., Needling furnishing fabrics and woven fabric-reinforced textiles, International Textile Bulletin, 2003, No. 2, 54-57.*
12. *U.S. Patent 6, 797,121 B2, Hyvönen et al., 28.09.2004.*
13. *Web site of Tamfelt Company, http://www.tamfelt.com, referred 07.04.2005.*

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