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Abstract

At the Institute for Printing Machines and Printing processes of the Technische Hochschule Darmstadt it was built an experimental set-up for on-press measurement of the ink film hardness on the running web. The main purpose is to develope a measuring device for the drying rate which can be used in the press during the production and can control the dryer to avoid waste by smearing. Up to date it does not exist another ink film hardness test method for on press measurements /1/. To test the hardness of the ink film a "smearing device" is pressed to the printed surface on the running web. When the ink film is not dry enough, some of the ink will be rubbed off. This rub off is detected electro-optically. In a first approach, ink from test marks was rubbed off by the smearing device and transfered to unprinted areas of the test zone where they were detected. Later another method was developed to measure the rubbed off ink directly on the smearing device. This second method is substantially accurater as the first one.

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Measurement of Ink Drying Rate on a Running Web

1. Description of the first version with electrooptical measurement on the web

This set-up tests the hardness of the printed ink film. If the ink film has not been sufficiently hardened by the drying process, the ink of test marks will be rubbed off and transfered to unprinted areas of the test zone. The smearing is optically detected.

A row of solid color bars was chosen as test marks like Fig. 1 shows.

The set-up was mounted on a model printing machine, of which the web is 90 mm wide. The place where the hardness of the ink film is mechanically tested was situated 2,7 m after the printing unit. The test is carried out with a "smearing device", which can be differently loaded and with which a shearing force is applied to the ink film.

When the ink film can not resist this load, the smearing device rubs off the ink and transfers it to the unprinted areas between the solid color bars. This smearing device contacts the paper on a line which is 1,5 mm wide and 46 mm long and is perpendicular to the motion of the web, covering the whole width of the measuring zone. Smearing pressures up to 40 Newton/cm^2 can be applied. An optical scanning unit is placed after the smearing device. It works with 45^o illumination and 90^o detection geometry.

The smearing leads to a little diminution of the light backscattering of the unprinted surface. It is important to measure a value which is independent of possible changes in the optical properties of the paper. changes in illumination etc. and which is only related to the change of the light backscattering caused by the smearing of the ink. To ensure that only this effect is measured, it was formed the following quotient:

$$Q = \frac{M}{R}$$

where M is a signal proportional to the light backscattered by the smeared areas and R a signal proportional to the light backscattered by a reference area (see Fig. 1) near the solid color bars. Both traces are illuminated with light coming from the same halogen tungsten or Xe-high pressure lamp. Therefore the quotient is independent of changes of the light output of the lamp.

An optical head (Fig. 1) detects light coming from a 0,1 mm times 46 mm area which corresponds to the width of the measuring zone. To measure colored inks complementary filters were used. In the optical head the light coming from the smearing trace is projected from an objective to one photodetector and the light from the reference trace to the other one.

The output of both photodetectors is amplified and sent to the main electronic box. Therein follows a digital evaluation of the signals to a quotient as explained before.

To give a normalized value of this quotient with possible values between 0% and 100%, the measuring system compares the new quotient with another one measured on the unprinted clean paper just before the printed zone reaches the optical measuring system (see Fig. 1).

The control marks printed on two traces on both sides of the measuring zone are also optically detected and give the necessary trigger and enabling pulses for the digital evaluation.

A LEDs display gives directly the computed value of the normalized quotient averaged over all the spaces between the solid color bars.

The diminution of the light backscattering is given by:

$$V = 100\% - Q \qquad (I)$$

The quantity V was called "smearing rate" (from the German "Verschmierungsgrad"). V is 0% for a completely hardened ink film and 100% for a hypotetical smearing which is comparable to the solid print. For the values of V with practical significance, up to some few percent, it can be assumed that V is proportional to the smeared ink amount per surface unit q_b

$$V = K \cdot q_b \qquad (II)$$

The error of the optical detection system by the measurement of V is 0,01%. But the optical uneveness of paper leads to much larger errors which can be reduced only by taking the average of the results of many measurements. The error of the average of 12 single measurements was about 0,05% on coated papers and 0,2% on uncoated papers.

To carry out a non destructive ink film hardness test it is necessary to measure smearings before the eye can recognize them. From which threshold a smearing can be perceived by the human eye depends on the paper and ink used, specially on the color of the ink. By our own experiments, it was found that this threshold is always greater than V = 0,1%. Therefore to carry out a non destructive test it would be often necessary to average over still a larger number of measurements.Repetitive misprints can also lead to errors in the order of 0,1%; therefore it is also necessary to use the following equation for V:

$$V = Q_o - Q_v \qquad (III)$$

where Q_0 is the quotient measured on an unsmeared printing and Q_v is measured on the smeared one. As result, to reach the wished accuracy, it could be necessary to average over a large number of measurements and to carry out twice a number of single measurements.

The before described experimental set-up was used to study the dependence of the smearing on different parameters as e.g. web velocity, ink film thickness and smearing load. The result of those measurements can be summarized as follows.

Dependence on the web velocity:

It was not found any dependence of the smearing on the web velocity. This means, with constant values of the smearing load and printing density, the measured smearing rate V is the same for the whole web velocity range of the used model printing machine, between 0,6 and 3,6 m/s. Therefore it was possible to chose a low web velocity of 0,84 m/s for the following measurements to minimalize the paper waste.

Dependence on the ink film thickness:

The ink film thickness was controlled through the printing density.

Fig. 2 shows the smearing as function of the ink film thickness, for both, coated and uncoated papers.

The bend in this curves may be interpreted as connected to the maximal ink quantity that can be absorbed by the paper.

Dependence of the smearing load:

This measurements, carried out on ink films under the bend thickness, show an increase of the smearing rate V with the load. The shape of V versus smearing load describes the smearing behaviour of an ink film, and in this it was possible to compare different combinations ink-paper, with or without drying. Although the curves V versus load brought useful information about the smearing behaviour of ink films, specially by larger loads, it was often very difficult or even impossible to evaluate the threshold load for smearing.

Fig. 3a shows an example for a black ink on uncoated paper. This paper seems to be optical even, and a good setting drying mechanisme requires loads over 2,5 N/cm^2 to produce some smearing. Here it is easy to evaluate the threshold load.

In the next example, Fig. 3b, it was printed with the same ink on a less absorbent optical uneven, uncoated paper. To estimate the threshold load a larger number of points is necessary.

Fig. 3c shows the results for the same ink on a coated paper. Low loads suffice to produce relative large smearings because the setting of the ink is more difficult on the less porous surface of this paper. The measuring points are not so spreaded as on uncoated paper; this is a consequence of the better optical eveness of coated papers.

Each point of Fig. 3 required 12 single measurements of Q_o and 12 single measurements of Q_v; V was calculated with equation (III), as difference of the averaged values of Q_o and Q_v. Therefore, for each point 24 single measurements of Q were necessary.

This first version of an apparatus for on-press measurements of the ink film dryness was used for several measurements related to the smearing behaviour of different combinations ink-paper /2, 3/. The apparatus worked satisfactory but the necessity to average over a large number of single measurements to reach the wished accuracy set limitations to the measuring velocity.

The electronic evaluation had additional an analog quotient output which should allow to study Q or V as function of the position along the web, for example, as function of the distance to a print, but the optical uneveness of paper made also those measurements very difficult.

2. Analysis of the smearing process and improvement by using a transparent smearing device

An explanation of the method used to overcome the difficulties caused by the optical uneveness of paper, this means, to improve the signal-noise ratio, requires a short analysis of the smearing process:

When a printed surface runs under the smearing device, and the ink is not dry enough, some of the ink will be transfered to the smearing device /4/.

After a printed surface, for example, a solid color print, the rubbed off ink will be transfered back to the paper producing a long smearing track. The smearing decrease with the distance to the printed area; its half value length[x)] was always larger than 50 mm. The backtransfer leads also to a steady diminution of the amount of ink of the smearing device, this can be mathematical expressed as follows:

$$-B \cdot \frac{d}{dx} q(x) = q_b(x) \qquad \text{(IVa)}$$

where q is the amount of ink per surface unit on the contact area of the smearing device, B the width of the contact area smearing device-web (Fig. 4).

Equation (IVa) can be integrated to

$$q(x=o) = \frac{1}{B} \cdot \int_o^{\infty} q_b(x)\ dx \qquad \text{(Va)}$$

Equation (Va) means that the whole amount of ink which will be later dispersed over a long smearing track is concentrated at the beginning of the back transfer on the narrow surface on which the smearing device contacts the web. The following

[x)] Half value length means the length along the web after the printed surface on which V decays to one half of its initial value.

estimation, equivalent to equation (Va), shows the order of this concentration effect:

$$q(x<x_h) \approx \frac{x_h}{B} \cdot q(x<x_h)$$

where x_h is the half value length of the smearing track and B the width of the contact area. With a 2 mm wide contact area x_h is always larger than 50 mm; therefore a concentration effect may be expected of 25 or larger. This means that if it would be possible to measure the ink directly in the zone where the smearing device contacts the web, the measuring result would be improved on a factor 25 or larger.

To detect the ink in the contact zone, a smearing device could be used which contacts the web with a transparent plate as Fig. 5 shows. For detection the same electrooptical measuring system was used which had been developed for the former measurements direct on the web /3/. Like in those measurements, the fluctuations of the light backscattering of the paper remain as a noise source. But the change in the light backscattering of the contact zone caused by rubbed off ink is much larger.

For the little amounts of ink that also on the smearing device may be expected, the following equations would be equivalent:

$$- \frac{d}{dx} q(x) = \frac{1}{B} \cdot q_b(x) \quad \text{(IVa)} \longrightarrow - \frac{d}{dx} VI(x) = \frac{1}{B} \cdot V(x) \quad \text{(IVb)}$$

$$q(x=o) = \frac{1}{B} \cdot \int_o^{\infty} q_b(x)\, dx \quad \text{(Va)} \longrightarrow VI(x=o) = \frac{1}{B} \cdot \int_o^{\infty} V(x)\, dx \quad \text{(Vb)}$$

where VI(x) is the diminution of the light backscattering for measurements through the transparent plate caused by the ink cumulated on the surface on which the glass plate contacts the web. Corresponding to (IIa) is:

$$VI(x) = K \cdot q(x) \qquad \text{(IIb)}$$

The quantity VI was called "integral smearing rate" (from the German "Integraler Verschmierungsgrad", see equation (Vb)).

To go on with this analysis two assumptions are introduced:

In the smearing process, ink is transfered from the smearing device only to the roughness peaks of an unprinted paper surface. The probability for this backtransfer should be also proportional to:

1_ The surface density of roughness peaks of the paper, which may be seen as a constant for each paper.

2_ The amount of ink on the smearing device.

If 1_ and 2_ are right, then should be:

$$- \frac{d}{dx} q(x) = - \frac{1}{x_o} \cdot q(x) \qquad \text{(VIa)}$$

where $1/x_o$ is a constant, proportional to the ink backtransfer ratio. From (VIa) and (IIb) can be obtained:

$$- \frac{d}{dx} VI(x) = \frac{1}{x_o} \cdot VI(x) \qquad \text{(VIb)}$$

Equation (VIb) can be integrated to

$$VI(x) = VI(x=o) \cdot e^{-\frac{x}{x_o}} \qquad \text{(VII)}$$

from (VII) and (IVb) can be also obtained:

$$V(x) = \frac{B}{x_o} \cdot VI(x=o) \cdot e^{-\frac{x}{x_o}} \qquad \text{(VIIIa)}$$

or

$$V(x) = V(x=o) \cdot e^{-\frac{x}{x_o}} \qquad \text{(VIIIb)}$$

with

$$V(x=o) = \frac{B}{x_o} \cdot VI(x=o)$$

For every x the following relation is valid:

$$VI(x) = \frac{x}{B_o} \cdot V(x) \qquad \text{(IXb)}$$

Briefly, the smearing process should always follow the equations

$$\frac{d}{dx} VI(x) = - \frac{1}{B} \cdot V(x) \qquad \text{(IVb)}$$

$$VI(x) = \frac{1}{B} \cdot \int_{x}^{\infty} V(x)\ dx \qquad \text{(Vc)}$$

If the smearing rate is proportional to the amount of ink on the contact surface of the smearing device, also the following equations should be valid:

$$VI(x) = VI(x{=}o) \cdot e^{-\frac{x}{x_o}} \qquad \text{(VII)}$$

$$V(x) = V(x{=}o) \cdot e^{-\frac{x}{x_o}} \qquad \text{(VIIIb)}$$

$$\frac{VI(x)}{V(x)} = \frac{x_o}{B} \qquad \text{(IXb)}$$

Equation (VII) and (VIIIb) say that the smearing rate on the paper and the amount of ink on the smearing device should decay exponentially with the distance x to a printed surface; equation (IXb) means that the ratio VI(x)/V(x) should be proportional to the decay length x_o.

3. Results obtained with a transparent smearing device

Fig. 5 shows the smearing device which was built to measure electrooptically through a transparent plate, on the contact surface between smearing device and web. A steel arm binds a frame with a glass plate to a rod mounted with bearings on both ends. The frame can also rotate on an axis along the steel arm, permitting the glass plate to press uniformly on to the web. The electrooptical measuring is done through the glass plate which contacts the web on a 2 mm wide zone over a metal roller.

With this device and by using the same electrooptical measuring system as before it was possible to reach a substantial improvement of the signal/noise ratio. By using the analog output of the electronic box now one can study the backtransfer process.

It was experimentally verified that the decay of VI(x) after a printed surface is indeed exponential one. Fig. 6 shows the results with a smearing load of 1,63 N/cm^2 for a conventional ink printed on an uncoated paper, where setting is the only drying mechanism (The same combination ink-paper as in Fig. 3b). The points of Fig. 6 were averaged over 5 decay curves after a solid color print. The relation between x_o and the half value length x_h is

$$x_o = x_h/\ln 2 = 1{,}443 \cdot x_h$$

For example, when x_h is 63 mm, as in Fig. 6, the decay length is 91 mm and for B = 2 mm the ratio VI to V is 45. It is well known that the signal/noise ratio improves with the square root of the number of averaged measurements. Therefore it would be necessary to average about 2.000 measurements to reach the same signal/noise ratio in case of direct measurement of V, if the optical uneveness of paper remains as main error source.

Actually, x_h depends not only on the used paper and ink but also on the smearing load. Fig. 7 shows the dependence of x_h over the load for the same paper-ink combination as in Fig. 3 and Fig. 6. In Fig. 7 can be seen that x_h, and then also x_o, may be very large for loads that are just sufficient to produce a smearing. The same is valid for the ratio VI/V.

With this knowledge of the smearing process it is possible to continue in the search for a method and the next development of an apparatus to measure on press the mechanical hardness against rub - off of an ink film. The hardness of an ink film could be described through the dependence of the ink amount transfered to the smearing device. This means through the curve VI(x=o) as function of the load. Such a measurement is equivalent to those of V as function of the load but with a higher sensitivity.

Fig. 8 shows the test print used with this aim. The measurements of VI, through the glass plate, is now also carried out between the solid color bars. If rub-off occurs, the amount of ink transfered to the glass plate reaches in the first, wide, solid color bar nearly its saturation value. In the space between the first and the second color bars, VI(x) remains very close to VI(x=o), because the distance between the bars is much less than x_h. From the second color bar the smearing device receives ink as compensation to those ink backtransfered between first and second bar; in the space between second and third bar is again VI(x) nearly equal to VI(x=o) and so on. Therefore a measurement of VI averaged over a solid color bar row will correspond to VI(x=o).

The length of the solid color bar row is about one third of the circumference of the cylinder. If x_o is one half or less of the distance between two rows of bars, the backtransfer will be nearly complete and therefore the smearing device cleans before the measurement of the next row is started. As Fig. 7 shows x_h and x_o may be for little loads too large. To guarantee a cleaning an extra load was applied after each solid bar row. To the smearing load, which was applied with weights, a cleaning load was superposed generated with an electro magnet on the steel arm of the smearing device.

Fig. 9 shows two examples of the dependence of VI over the smearing load. It is not more necessary to compare the quotients with and without load on the smearing device, as in equation (III), because the measured values of VI are clearly larger than 0,1%, even for very little smearing on the paper, and VI can be computed as the difference between 100% and the measured quotient. It remains necessary to average over some single measurements because the smearing process itself is stochastic. Therefore, the improvement of the signal/noise ratio by measuring through the smearing device is often less than x_0/B. For each point of Fig. 9 it was averaged over 8 single measurements.

Fig. 9a shows the result of measurements with the same combination uncoated paper-ink as used in Fig. 3b, Fig. 6 and Fig. 7. Fig. 9b shows the results for the same uncoated paper printed with a uv-curable ink.

The uv-cured ink can withstand the applied shearing load. In the other two cases, the threshold load for ink transfer to the glass plate can be clearly seen. After this point there is a linear increase of VI with the load, when a square root scale for the load axis is used. It is not clear, why a square root scale on the load axis is needed to obtain such a linear increase of VI after the threshold load. This behaviour was stated for every tested combination ink-paper.

The dryness of the ink can also be described with two numbers, who characterice VI as function of the sqare root of the load after the threshold load and the load which is necessary to reach VI=2,5% were chosen.

When the hardness of the ink film increases, both, threshold load and load for VI=2,5% increase: For the control of dryers it seems to be suitable to set the control loop at VI=2,5%. As said:

$$\frac{V}{VI} = \ln 2 \cdot \frac{B}{x_h}$$

As x_h is always larger than 50 mm, and a smearing device with B=2 mm is suitable for the electrooptical measurement, V would remain under 0,07% for VI=2,5%. Therefore, with the set point of the control loop at VI=2,5%, a non destructive measurement and control would be possible because the human eye cannot preceive a smearing under V=0,1%.

This works are been continued with the goal to carry out the measurements directly on the printing product of production presses instead of doing it on test prints in a model printing machine.

For the method of measuring the drying rate of an ink film on press, which was described in this paper, a patent application was filed.

4. References:

/1/ W. Heckers, Bewertung von Trocknungsverfahren (Valuation of drying rate measuring methods), Institut für Druckmaschinen der Technischen Hochschule Darmstadt, Diplomarbeit, Darmstadt, Federal Republic of Germany, 1975

/2/ M. Glück and J. Rodriguez-Giles, Measurement of ink drying rate on a running web, IARIGAI Symposium "Web-press instrumentation and automation", Otaniemi, Finnland, 1978

/3/ M. Glück and J. Rodriguez-Giles, Beitrag zur Messung des Trockengrades eines gedruckten Farbfilmes an der laufenden Papierbahn (Contribution to the measurement of the drying rate of a printed ink film), Institut für Druckmaschinen und Druckverfahren der Technischen Hochschule Darmstadt, Institutsbericht 1/1979, Darmstadt, Federal Republic of Germany

/4/ L.O. Larsson and E. Wallner, The mechanism of rub off from a printed surface, 10th International Conference of Printing Research Institutes, Austria, 1969

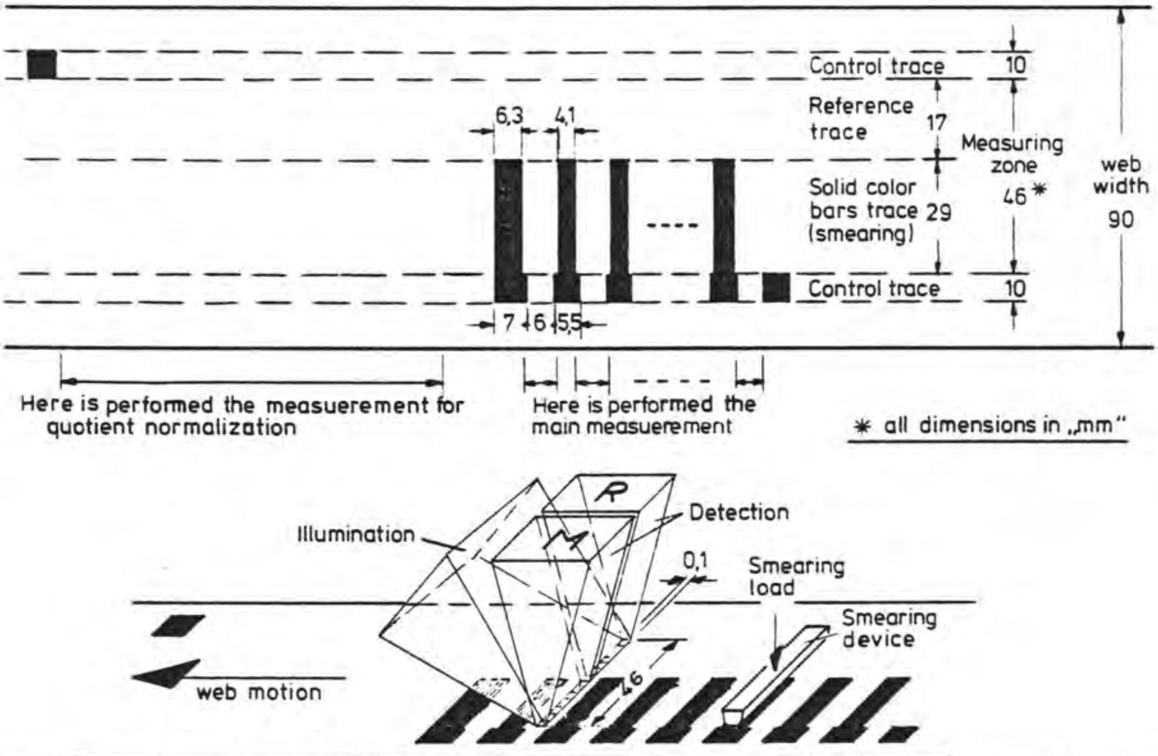


Fig. 1 Row of solid color bars used as test print for ink film dryness measurements and principle layout of the measuring system

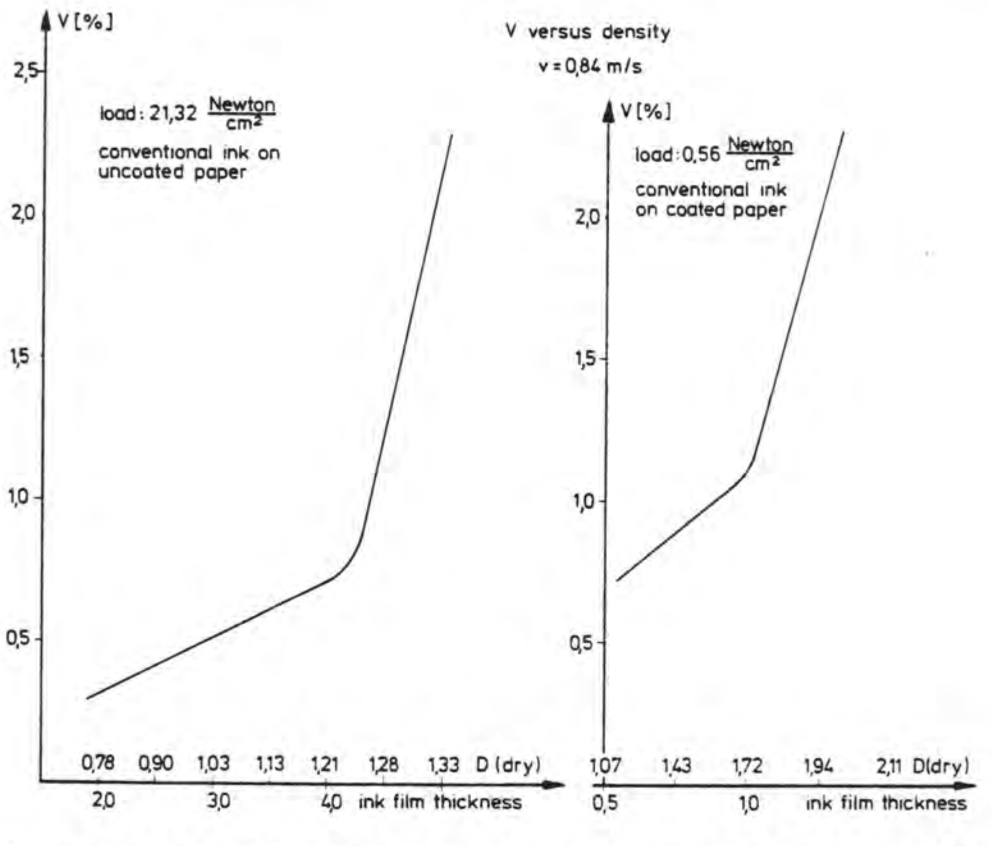


Fig. 2 The smearing rate V as a function of the ink film thickness

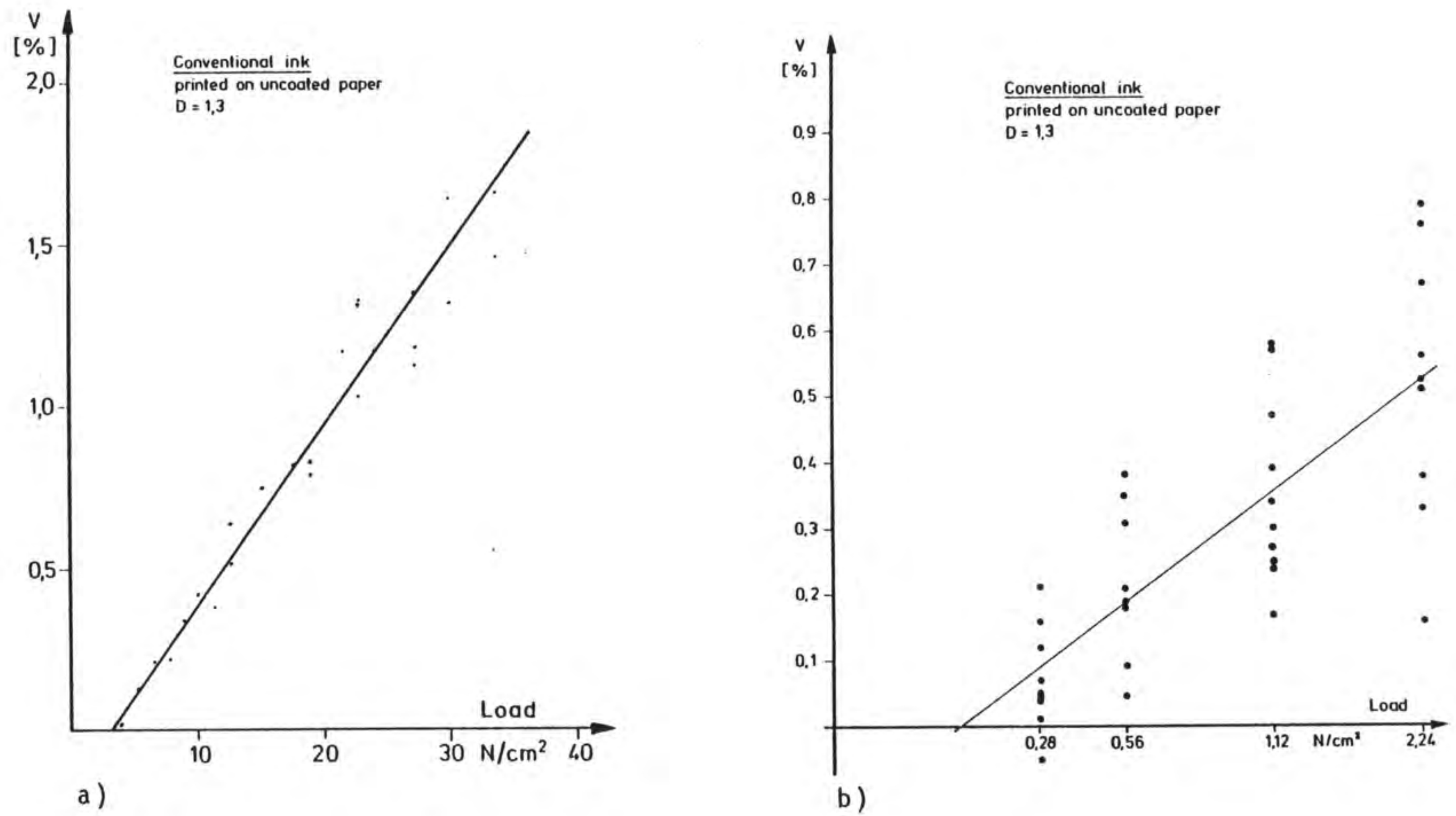
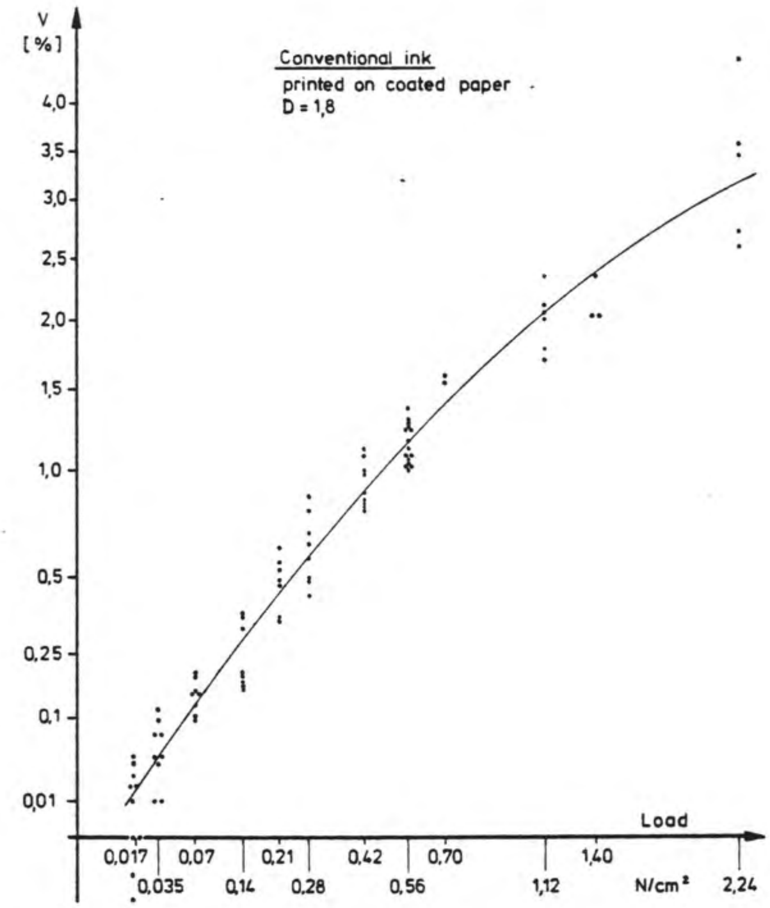


Fig. 3 The smearing rate V as a function of the smearing load. The uncoated paper of a) shows a better setting behaviour as the uncoated paper of b). For the load axis of b) and c) and the V axis of c) a square root scale was used.


V
[%]
Conventional ink
printed on coated paper
D = 1,8
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,25
0,1
0,01
Load
0,017
0,035
0,07
0,14
0,21
0,28
0,42
0,56
0,70
1,12
1,40
N/cm²
2,24

3 c)

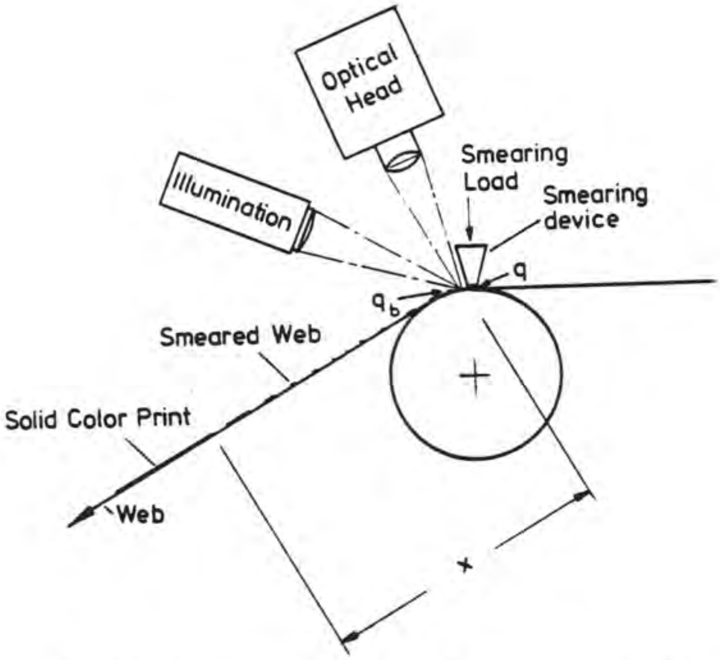


Fig. 4 Backtransfer of ink after a printed surface.

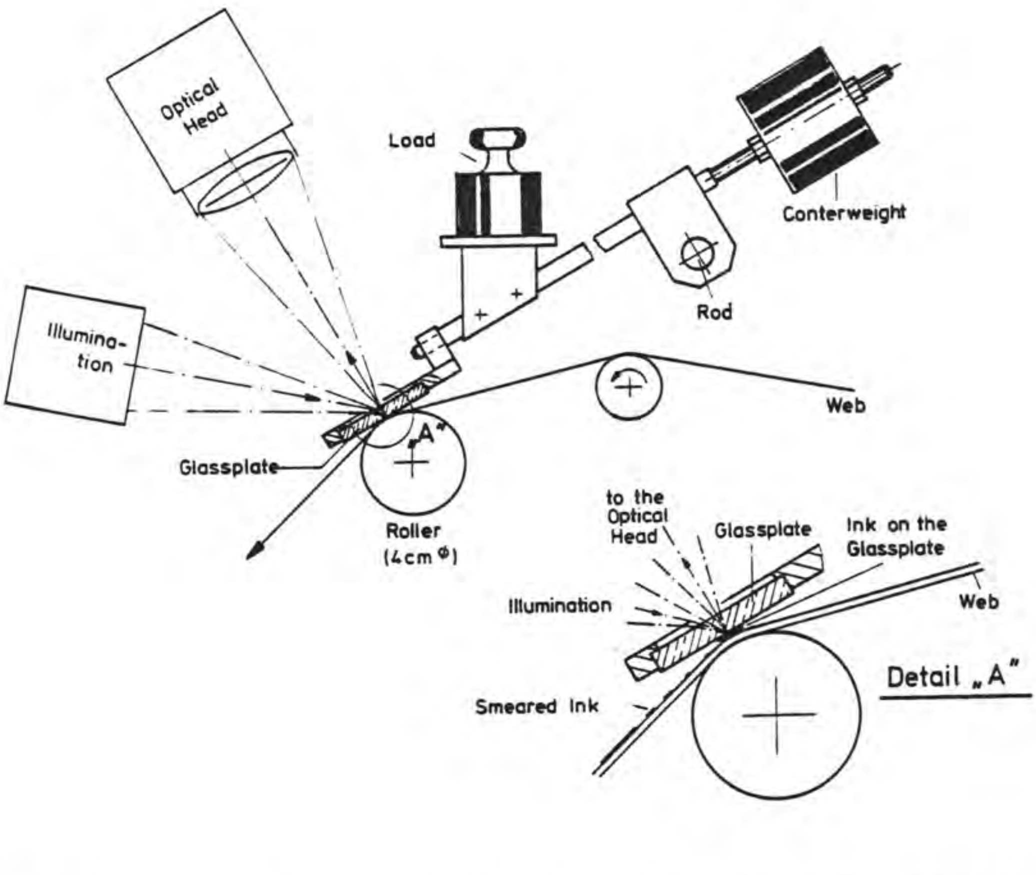


Fig. 5 Smearing device with transparent plate for direct measurement of the integral smearing rate VI

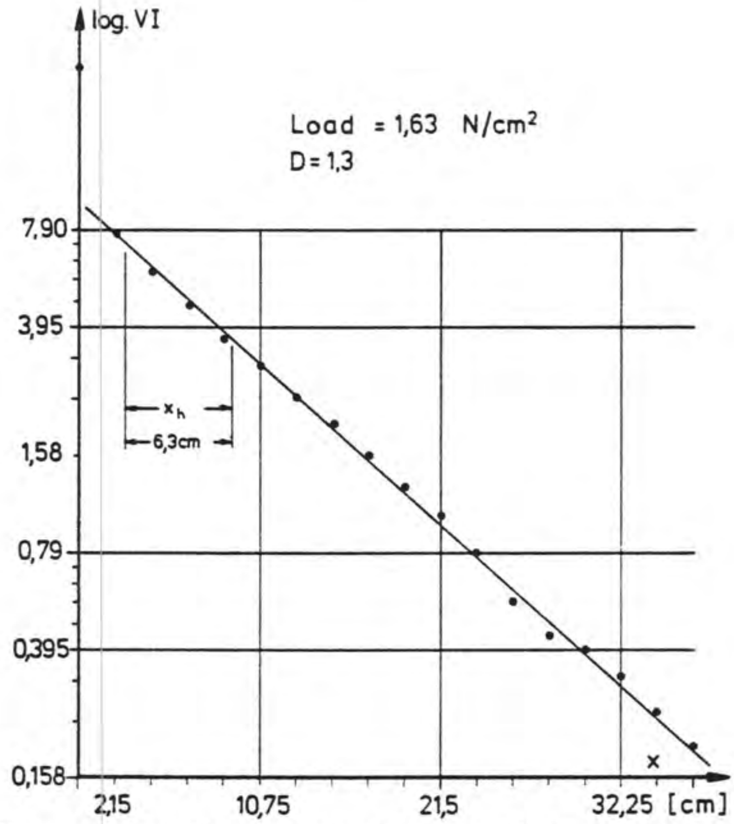


Fig. 6 The integral smearing rate VI as a function of the distance x to the solid print

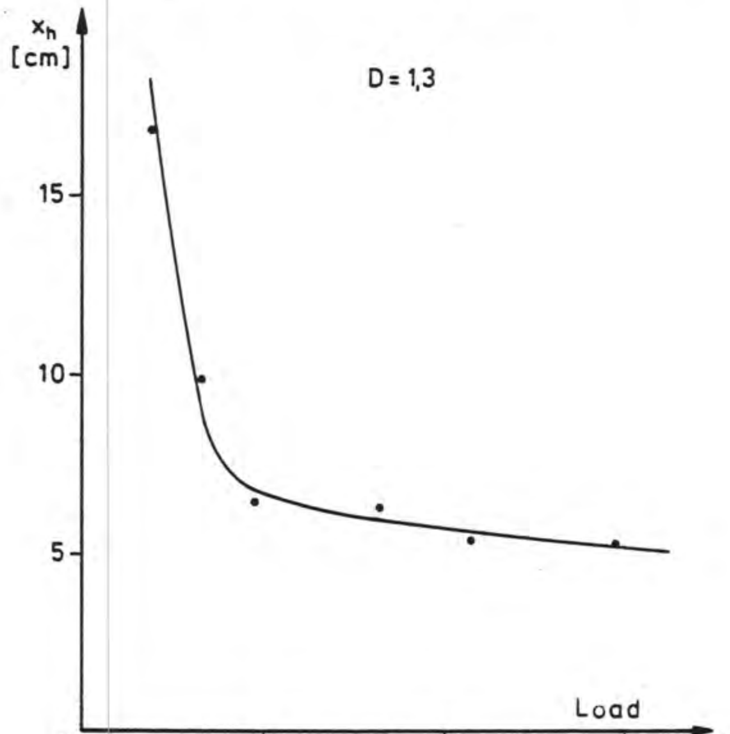


Fig. 7 The half value length x_h as a function of the load

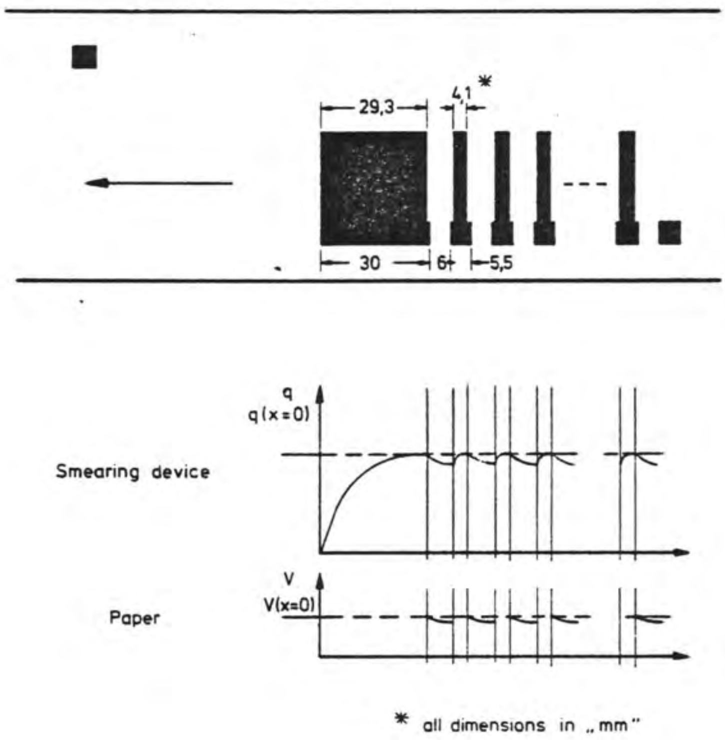
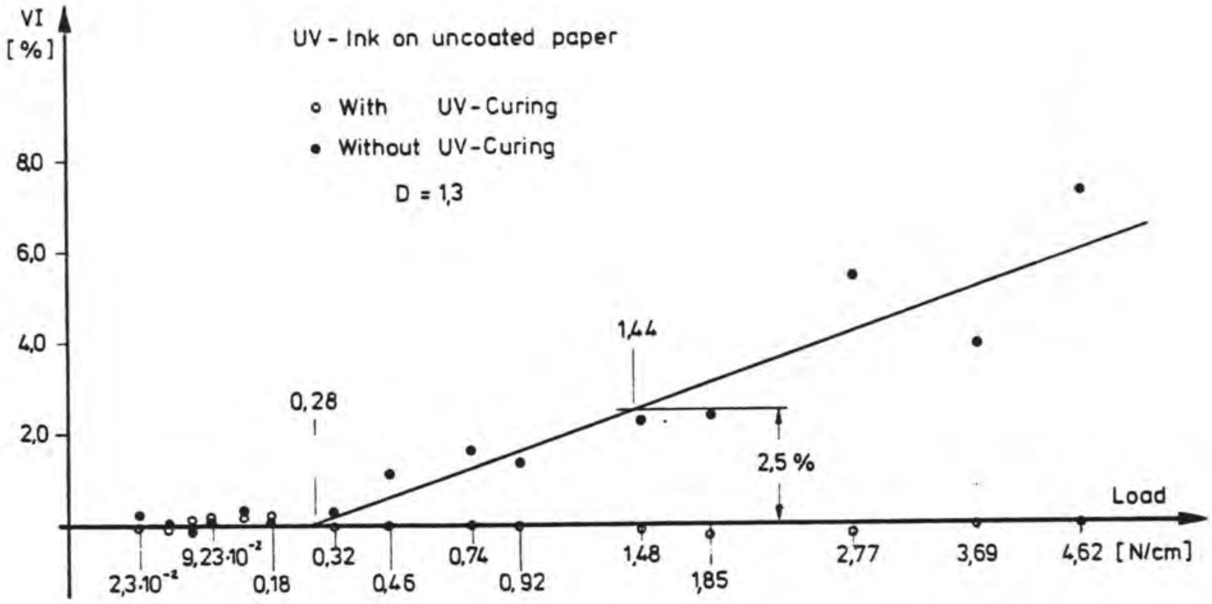
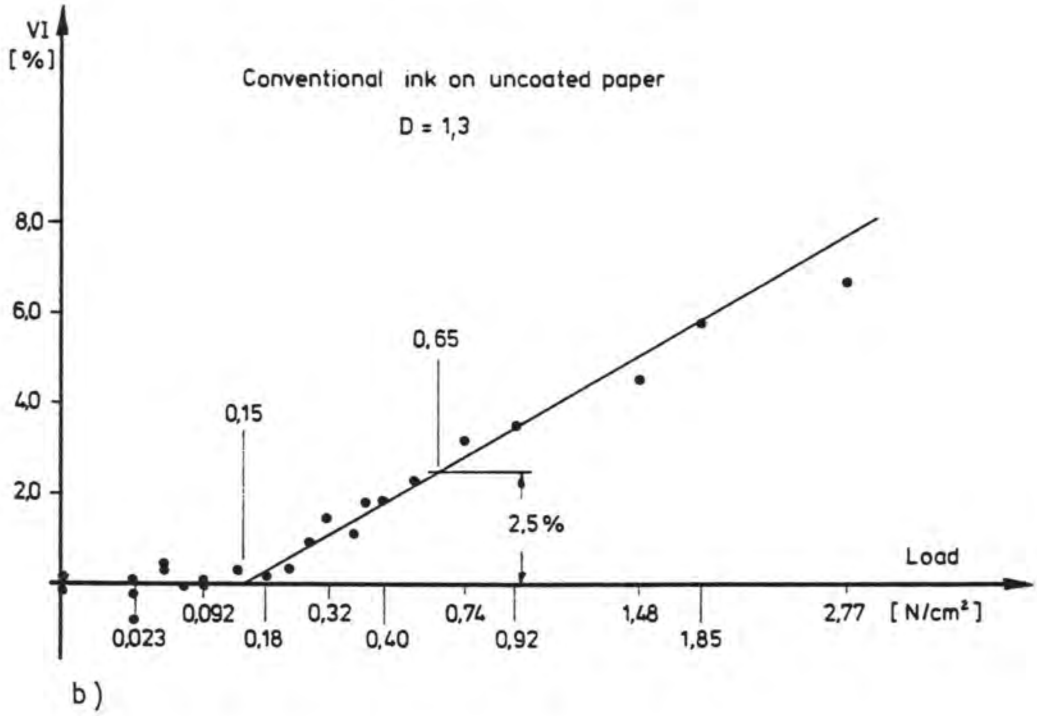


Fig. 8 Test print used to measure the integral smearing rate VI as a function of the load



a)



b)

Fig. 9 The integral smearing rate VI as a function of the load. A square root scale was used for the load axis.