Development of a method for pre-damping in laboratory offset printing units

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SUMMARY

At the Iggesund mill there are several methods and equipments in laboratory scale that simulate the offset printing process in order to evaluate mottle tendency or ink tack for instance. However, it is not possible to study the effect of pre-damping prior to printing on these properties, which mostly is the case in industrial printing.

The purpose of this work was therefore to develop a method for pre-damp application used prior to laboratory offset printing in order to learn more about the ink/fountain solution/substrate interaction. This method was used to study the effect of pre-damp on ink tack measurements and on water interference mottle tendency in laboratory scale.

The initial trials were focused on ink tack measurements without pre-damp in order to achieve knowledge about this type of measurement. The effect of different parameters used within the ink tack measurements was also investigated.

The ink tack measurements were rather sensitive to the method of ink distribution procedure, the positioning of the tack disc and the fastening of the paperboard sample. Additionally, the printing speed, the printing pressure and the hold time affected the measurements. However, measurements in the cross direction and the machine direction of the paperboard were compared, and did not show a significant difference. Different levels of tackiness of the ink were also tested. For instance, an ink that previously had caused delamination failure in industrial offset printing showed a relatively high ink tack.

Four different paperboard qualities were also compared. The small differences in ink tack between the samples were explained by the differences in coating characteristic resulting in different ink absorption.

The same paperboard qualities were also used in an inter-comparison between different laboratories measuring ink tack (Iggesund, STFI and Imerys). The same machine settings and the same type of ink was used in the investigation. Although the four qualities always were ranged in the same order, both the level and the shape of the ink tack curve differed in between the three laboratories. One explanation given was that different tack discs were used in the investigation.

The method developed for pre-damp application was based on condensation of a water film on a cooled down metal disc. The effect of the temperature on the metal disc surface (inside a fridge), the dwell time inside a desiccator and the time for condensation in a conditioned room on the amount of water developed on the disc surface was investigated. The amount of water developed and transferred could be related to the resulting print density or transferred ink amount. A lower print density or transferred ink amount implied a larger amount of water applied to the sample. The experiments showed that this procedure is rather uncertain and that the tests are difficult to reproduce. However, a lower temperature of the damp disc inside the fridge in general resulted in a larger amount of water developed onto the disc surface.

The pre-damp application was used prior to printing and ink tack measurements. The maximum and the shape of the ink tack curve only changed slightly when using pre-damp in comparison to the measurements without pre-damp. In general, the ink tack curve in the later phase was lowered when using pre-damp, indicating a faster ink setting and drying. This may be attributed to that the viscosity of the ink decreases when blended with water. Another explanation given was that penetration of water into the substrate leads to swelling and consequently a rougher surface and a lower ink tack. A lower amount of ink transferred in some cases may be another explanation.
The pre-damp was also applied prior to printing in Prüfbau in mottle evaluations, creating water interference mottle. Two paperboard samples with different levels of performance in industrial printing were compared. The sample with less good performance also appeared worse in this investigation with respect to mottle, both with and without pre-damp before printing. This sample had lower coat weight according to burn out pictures and also a lower contact angle in comparison to the better sample.

A correlation was also achieved between the water interference mottle tendency obtained in laboratory printing and in a full scale printing trial, respectively. Only three qualities were included in this investigation. Further experiments must be performed to really see the correlation between these two methods.
Preface

This master thesis is the final assignment for the Master of Science in Chemical Engineering at Luleå University of Technology. The thesis is done at the department of Chemical Technology at Luleå University of Technology and the Product development centre (PDC) at Iggesund paperboard. The title is Development of a method for pre-face application in laboratory printing.

Several people deserve credit for their encouragement and help. First of all I would like to thank all the staff at the Product development centre at Iggesund paperboard for giving me the opportunity to do this master thesis and specially my supervisor Anna Lund for her guidance, help and support during the writing of this thesis. I also would like to thank the people I have been in contact with at the Product and technology development centre, for all the help with my thoughts and questions, particularly Niclas Hagström and Anita Wahlström for all their help and support with all the practical issues, thank you.

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1 INTRODUCTION

In offset printing, the interaction between the printing ink, the fountain solution and the substrate is critical. An unfavourable interaction between these parts may cause runnability and printability problems during the printing procedure. In the offset press, the fountain solution is applied on the printing plate to keep the non-printing areas free from ink, but also to control the properties of the printing ink, for example viscosity and ink tack. However, the fountain solution may also cause some problems that the printer has to adjust for.

For instance, the wrong amount of fountain solution may affect the absorption properties of the substrate so that setting and drying of the ink becomes critical. If the ink tack or the viscosity of the ink becomes too high, the substrate may be subjected to delamination failure. A print related problem called mottle, referred to as variation within print density or gloss, may also occur on the printed substrate (paper or paperboard), with or without water involved. When the fountain solution is the cause for this mottle problem, it is referred to as water interference mottle.

In order to understand this problem better, and to improve the paper and paperboard surfaces, it is necessary to study the limitations and relations within the interaction ink/fountain solution/substrate.

At the Iggesund mill there are several methods and equipments in laboratory scale that simulate the offset printing process in order to evaluate mottle tendency or ink tack for instance. However, it is not possible to study the effect of pre-damp prior to printing on these properties.

The purpose of this work was to develop a method for pre-damp application used in laboratory offset printing in order to learn more about the ink/fountain solution/substrate interaction.

The objectives were:

- To develop a method for damp application that can be used prior to different laboratory offset printing applications.
- To study the effect of pre-damp on ink tack measurements.
- To study the effect of pre-damp on mottle tendency in laboratory scale.
2 ABOUT IGGESUND PAPERBOARD AB

The town Iggesund is situated on the coast of Hälsingland, about 3 hours north from the capital Stockholm. Hälsingland has due to its location always played an important roll in the wood and paper industry in Sweden.

The birth of Iggesund papermill goes back to 1572, when the first crown-sawmill in the northern Sweden was established. At 1748 the first paper mill was established in the area were the mill is situated today. This double cutting and rolling mill was also the first one in Sweden. The first (KM1) of two paperboard machines was taken in to service in 1963, the second one (KM2) in the beginning of 1971.

Iggesund Paperboard AB is one of the largest manufacturers of virgin fibre paperboard in Europe, with production plants located at Iggesund in Sweden and at Workington in Great Britain. Sales offices are located in different parts of the world. The company also has a specialist conversion plant located at Strømsbruk in Sweden, where paperboard is extrusion coated and laminated with a range of plastics and metal foils for applications requiring specific barrier or promotional properties.

Iggesunds Bruk is the largest paperboard mill and production plant in Iggesund Paperboard AB, and it produces solid bleached board. The product quality is Invercote.

The different types of solid bleached board in Invercote are Albato, AT, Creato, Creato Glossy, G, Lenato, Octo, T, TB, Polyboard and Foldcart.

The different usage areas are packaging, graphic and tobacco. Packaging includes pharmaceuticals, perfumes, cosmetic, chocolates, wines & spirits. In graphic usage areas are covers, cups, cards, folders, food packages. The grammage range of Invercote is between 180-380 g/m².

Workington is a paperboard mill and is located in UK. Workington produces folding boxboard. The product quality is called Incada, with the type Silk, Silk T and Exel. It has the same usage areas as the Invercote product. The grammage range of Incada is between 200-350 g/m².

Strømsbruk is the conversion plant and uses the board from Iggesund and Workington for plastic coating (PE, PP and PET coating) and also lamination (Alubarrier, Aluvision and Metalprint). End-use areas are advertising materials, games, CD-holders, drinking cups, confectionery, packages for wet products, ready-made canteen food for convection ovens, microwave food, biscuits, cups and tubs.
3 LITERATURE STUDY

3.1 The History of the Lithography

A law student at the University of Ingolstadt in Germany invented the lithography process during the late 1700. The student Alois Senefelder was a playwright and got his play “Die Maedchenkenkenner” published. The play became successful, and he made a proper profit, which convinced him that he found his “call in life”. Although the following plays did not reach the same success, he did not blame himself, since he was convinced that he was born a playwright, but he did blame the high cost of printing that caused him the financial strain. The art of printing seemed to him a simple task and he studied it in order to be able to write and print his masterpiece to endure his art of living.

During this time the most common printing technique was the copperplate engraving. All the costly engraving errors he made engraving the copperplates, forced him to try other materials. He found a material called kellhein stone, from a local limestone quarrel. The stone was easier to engrave and was simple to polish in order to form a perfect surface. It was in the end, an episode with his mother, and the lack of paper, that made him come up with the final stage towards lithographic printing.

“As the matter would not admit the delay, and we had nobody in the house to send for a supply of the deficient materials, I resolved to write the list with my ink prepared with wax, soap and lampblack, on the stone which I had just polished, and from which I could copy it at leisure.” (International Paper, 2003)

This invention and the fact that he realized that “oil and water do not mix”, became the starting point of his invention. He called his invention “lithography” (from Greek, litho meaning limestone and graphein, meaning stone writing). After years of experimentation, he developed a mixture of gum and water that he coated the stone, which during moist conditions would repel ink. Mr Senefelder’s invention is the first step towards today’s offset printing.
3.2 Coated paper and paperboard

Paper and paperboard are made from cellulose fibres that are extracted from soft wood and hard wood in different processes in the pulp industry (Fellers and Norman 1996). The main difference between paper and paperboard is in grammage and also the amount of layers the material is built up of. Paper normally consists of one layer and paperboard of several in order to reach the requested grammage and functionality.

It is important to have a high quality base paper for the coating procedure in order to create a smooth surface and to avoid web breaks during the actual coating in the machine.

Some of the important characteristics for the base paper and base board are:

- Brightness
- Opacity
- Porosity
- Strength
- Formation
- Surface roughness

High brightness of the base paper is important since the coating layer is thin. A yellowish base paper may shine through the coating layer.

Opacity is the ratio of light reflected from a single sheet of paper placed over a black background and the light reflected from a pile of several sheets. Low opacity on a magazine for instance, means that it is possible to see through the sheet, almost reading the text on the reverse side. High opacity is desirable for a good printability.

The level of the porosity in the base paper is important. If the porosity of the base paper is too high the coating may set too deep into the base paper resulting in a bad printing. Base papers with high strength reduce the risk of breaks to occur during the coating process. The strength is partly related to the formation of the fibres in the base paper. A poor formation may lead to an uneven coating distribution, which may be seen as streaks in the coating layer.

The surface roughness of the base paper is of high importance for the final result of the coating procedure. An uneven surface may lead to a thickness variation in the coating layer, which may lead to an uneven printing image. Figure 1 shows a schematic drawing on a cross-section of a coated base paper, with thickness variations within the coating layer due to the coating on an uneven base paper. A uniform level of moisture in the base paper is also important in order to give suitable absorbent characteristics.

![Figure 1. A schematic drawing of a cross section of coated base paper.](image)
The coating structure has better absorption properties for ink setting comparing to the cellulose fibre structure. The coating enables the different components in the ink to stay on the surface. A high print quality requires some of the following paperboard parameters: high smoothness, low porosity, good formation and high gloss. These quality parameters are difficult to achieve with base paper without coating. A coated fine paper normally contains of 80% base paper and 20% coating, while for paperboard, the part of coating is less due to the higher total grammage.

3.2.1 Coating composition and characteristic

The main component in coating is pigments (80-95 weight-%), binders (1-10 weight-%) and additives (Walter 1993).

Important characteristics for pigments are density, particle size, shape and opacity. The main pigments within coating are kaolin (used for improving the gloss and the printability), calcium carbonate (contribute to brightness), titanium dioxide (improved brightness and opacity), talcum and gypsum. Low density gives a more porous coating layer. High density improves the packing of pigment which is positive for coverage (Olsson 1999). Small particle size improves the opacity and gloss but increases the amount of binders needed. The shape of the clay particle affects the gloss of the coated paper. The aspect ratio, quotient between the particle diameter and its thickness, is normally used in order to describe different kinds of clay mixtures. High aspect ratio increases gloss due to improved coverage. Figure 2 shows a kaolin particle marked with the dimensions used when calculating the aspect ratio.

![Figure 2. The aspect ratio described for a clay particle.](image)

Binders are divided into two different groups, water soluble binders or plastic dispersions (latex). Their purpose is to bind the pigment particles together and to establish a good bonding between the coating layer and the base paper. Among the water soluble binders there are two types, natural (starch or protein) or synthetic (CMC or PVOH). The water soluble binders have the ability to keep the water in the coating mixture and give excellent water retention. Latex is synthetic polymer dispersion and is the dominant synthetic binder used in the papermaking industry. It was developed during the 2nd World War as a replacement for rubber (Walter 1993).

The synthetic latices contain plastic particles dispersed in water, which form a film by fusion of the plastic particles as the water evaporates. The properties of the films, such as hardness, flexibility, toughness, adhesion, colour retention, and resistance to chemicals, depend on the composition of the polymer dispersion. Polymers based on styrene, butane, vinyl acetate, and
acrylic monomers are used commercially. Normal density of latex is about 1000 kg/m³ and the particle size is between 0.1-0.2 µm. A small particle size gives a higher binding strength than using large particle size.

The coating rheology is important in order to achieve an even coating layer on the substrate as well as good runnability on the paper and paperboard machine. One critical part where the rheology plays an important roll in the coating process is the situation under of the coating blade, the blade that applies the coating mixture onto the base paper. The coating mixture does seldom act like a Newtonian fluid, and in order to describe the viscosity characteristics in the coating mixture, viscosity during different shear velocities need to be measured. The coating mixture may have different characteristics, Newtonian, plastic, pseudoplastic, dilatants or thixotropic fluid. It is essential to maintain high dryness of the coating mixture in order to reduce production cost and also to attain proper rheology characteristic of the coating colour.

3.2.2 Calendering procedure

The base board surface can be improved prior to the coating process through pre-calendering procedure. The coated surface can be even more improved through final calendering after the coating process. In calendering the paperboard goes through one or several nips between cylinders. The pressure in the calender nip as well as a high temperature on the cylinder, results in a smoother paperboard surface and a higher gloss.
3.3 The Offset printing process

All offset printing presses today use the same lithographic principle invented by Mr Senefelder. Today’s high demands on productivity in the printing process have developed a process using curved cylinders instead of use of a flat plate. When describing the process the paper and paperboard is referred to as substrate.

3.3.1 Principle

Figure 3 shows a schematic drawing of an offset printing nip. Offset is an indirect printing process; the picture is transferred (offset) from one surface to another. Ink and fountain solution is transferred via plate cylinder carrying the image area to a rubber blanket. The image area is then transferred to the substrate in the nip between the blanket cylinder and an impression cylinder. An industrial offset press normally consists of at least four such printing nips (later shown in Figure 5).

![Figure 3. The offset printing nip.](image)

The lithographic principle is based on the ability to divide the image area and non-printing area by different chemical characteristics. The image area on the plate cylinder usually consists of a polymer layer and the non-printing area of aluminium, resulting in hydrophobic and hydrophilic areas respectively.

Figure 4 shows schematically the surface of the plate cylinder. The image areas (hydrophobic) attract the printing ink which is greasy or oily, while the non-printing areas (hydrophilic) repel the printing ink but attract the fountain solution.

![Figure 4. The behaviour of moist and ink on a plate cylinder with hydrophobic and hydrophilic areas respectively.](image)

In order to understand the behaviour of the ink and fountain solution we need to discuss their specific characteristics.
3.3.2 Cylinders

In order to achieve a proper ink transfer to the substrate, the three cylinders are forced together creating a high pressure on the surface. The printing cylinders are often stacked on top of each other, as shown in Figure 3, in order to create and control the pressure between the cylinders as well as onto the substrate. However, there are also other configurations used in industrial printing not discussed in this report.

The plate cylinder receives the ink and the fountain solution and transfers it to the blanket cylinder, which subsequently transfers the image to the substrate. The plate cylinder is manufactured from aluminium sheets.

The blanket cylinder has a layer of rubber composite. The reason for that is to receive a good image from the plate cylinder onto the blanket surface as well as to achieve good contact in the printing nip between the compressible blanket and the substrate.

The impression cylinder consists mainly of aluminium. The purpose with this cylinder is to contribute to the pressure loaded on the substrate in the printing nip, but also to hold the substrate in place to enable the blanket cylinder to maintain a high quality offset print.

An optimal compression of the rubber blanket in the printing nip creates a high ink transfer and a correct printing finish. Too high pressure in the printing nip results in an extended rubber layer on the blanket cylinder which creates an extended image on the substrate. The structure of the rubber affects the quality of the print. The rubber layer normally compresses about 0.1 mm in the printing nip (Olsson 1993). This results in a line load of about 70-200 N/cm in the contact zone, which usually is required in order to achieved a sufficient ink transfer. Low compression results in poor ink transfer from the plate cylinder.

3.3.3 Industrial offset printing

According to Scarlett and Eldred (1984) there are two different types of offset printing, sheet-offset and roll-offset. In Scandinavia, sheet-offset is the most common one and the report will therefore focus on this technique.

The modern sheet-offset printing presses have a large variation in press configuration such as print on one side or two sides during the process, and can easy adjust depending on the paper and paperboard grammage.

Normally offset printing presses only use four different colours but can use up to seven depending on the type of product (Johansson et al. 1998). The colours used are black, cyan (blue), magenta (red) and yellow and are placed in that order starting with black, depending on the different characteristics of the ink. Black is the stickiest ink with high viscosity and yellow have the lowest viscosity. Depending on the percentage of the four different colours on the same place on the print, a multicolour image is created.

When a larger amount of different inks is printed in the same image, different problems may occur during the printing process. Such a problem may be ink set-off on the parts where ink is not desirable, creating discoloration, and also picking which means, losses of fragments from the coating that creates dots on the printed image.

*Figure 5* shows a sheet-offset printing press. The sheets are stacked in a pile in the beginning of the press (right) and are fed into the press one by one, from right to left. Transported and passing through the different printing nips, the printed sheets are then stacked together in a new pile at the end of the line (left). The normal speed in an sheet-offset printing process is 11000-13000 sheets/hour.
When the printed substrate end up in the end of the press it is important to check that the desirable values of different parameters are achieved.
When creating the image exposure on the plate, the printer includes some test strips along one side of the sheet. This test strip shows the different colour combinations as well as the colour patch. Directly after the press, the printer takes random sheets and measures for instance colour density and balance. The printer also checks that the printed images agree with the desirable image. The press can easily be adjusted in order to create the image the customer wants.

3.4 Offset Inks

The most important characteristics of a printing ink are:

- Colour characteristics
- Physical characteristics
- Drying characteristics

The **colour** must agree with the desirable colour of the specific print and saturation. The characteristic of the colour is dependent on the pigment. In order for the pigment to “stick” on the substrate, binders are added. The binder makes the pigment buoyant and gives it its lithographic characteristics.

The **physical** characteristics such as viscosity and the flow of the ink are also dependent on the binder composition.

When ink comes in contact with a substrate, paper or paperboard, the liquid phase of the ink is absorbed into the coated substrate by its pores in the surface and the pigment and the binders stay on the surface forming a film. This **drying process** is important to understand in order to secure that the ink sets properly. If the liquid phase do not absorb suitably, printability problems related to ink setting and ink drying may occur, as well as runnability problems like delamination failure due to high viscosity and tack of the ink.

3.4.1 Composition

The ingredients in the ink are dependent on the type of use. In offset printing the main parts are pigment and binders.

**Pigment** is the most important substance in the ink, it gives the ink its visual identity (colour). The pigment can be natural or synthetic, where the synthetic pigments are most commonly used in offset printing. The amount of pigment in offset printing is higher than in other processes. This is because a lot of the ink in the process does not reach the substrate which is the case in direct printing processes.
Pigments are classified into two different groups:

- Inorganic
- Organic

The **inorganic pigments** consist of different metal compounds. Due to their high density and poor printing capacity, organic pigments in today’s printing processes mostly replace the inorganic pigments. **Organic pigments** also provide stronger and brighter colours.

According to Liiri Brodén *et al.* (1996) pigment consists of a mixture of primary particles, aggregates and agglomerates. The primary particles can have different shape such as spherical and irregular and they flocculate together into aggregates and agglomerates. Aggregates are a group of particles that are bound together side by side whereas agglomerate flocculates together edge by edge. *Figure 6* shows the different kinds of particles in the ink.

![Figure 6](image.png)

*Figure 6. A picture of primary, aggregate and agglomerate particles. (Liiri Brodén *et al.* 1996)*

Small pigment particles are required for ink. The larger the pigment particle size, the higher the tendency that the pigment stuck onto cylinders and rolls in the printing press (Liiri Brodén *et al.* 1996). Variation in the particle size affects the colour intensity as well as coverage ability. The reflective index influences the opacity of the pigment. If the pigment and the binder have the same reflective index, the light will go directly through the emulsion, hence the emulsion will be transparent. A higher difference in index gives more opaque printing ink film. The pigments must be resistant to chemicals and water, and the ink has to be stable during the printing process as well as during the drying stage. The dry ink has to be able to resist changes during exposure to water, soap, light, fat, grease etc.

The main task for the **binder** is to carry the pigment particles through the printing process, then dry and keep the pigment on the printed surface. Binders also influence the ink properties such as gloss and firmness. In order to achieve maximum colour of the pigment, the binder needs to wet the pigment properly.

The binder consists mainly of rosin, oils and solvent including waxes and softener (Scarlett and Eldred 1984). The task of the rosin is to bind the ink to the substrate surface after drying. It affects the speed of the ink drying as well as the final gloss of the print.
3.4.2 Rheology of offset inks

The ink rheology describes how the ink reacts and flows in the printing process. The two most essential rheology components that are discussed in this chapter are viscosity and elasticity. Viscosity describes the ink flow and the elasticity describes the structure and the tack during the process. Fu et al. (1994) describe ink rheology and how the ink react and flow in the printing nip. During the printing process the ink is affected by large forces. The ink is forced to deform between the cylinders, the cylinders are pressing the ink against the paper and the offset print is formed. Depending on the viscosity and the elasticity of the ink as well as the surface structure of the paper, the ink sets differently onto the paper and the ink film splits after the nip.

The shear stress on the ink fluid depends on the type of flow that occurs during the printing process. In laminar flow, the fluid flows in level layers and the shear stress is dependent on the molecules in the ink. In turbulent flow the fluid acts according to the fluctuations within the fluid and the flow properties, and the shear stress is a result of these fluctuations.

The wettability of the coated substrate is dependent on the ink/fountain solution/substrate interaction. The receptive layer in the substrate is porous and enables drainage of the ink binders and the fountain solution. Most of the ink in offset printing is designed to dry by absorption. The solvent (carrier phase) used in offset inks are mineral and vegetable oils. It is known that water and oil do not mix. However, when mixing the fountain solution and the ink under shear stress an emulsion is formed during the printing process. Depending on the components in the emulsion, different levels of interactions occur between the ink and the substrate.
3.5 Fountain solution

The fountain system is a dampening system, which stores fountain solutions. It is applied as a thin layer onto the plate cylinder before the ink application.

The main purposes of the fountain solutions are to:

- Assist in the distribution of ink in only the hydrophobic areas.
- Keep the printing plates and rubber blankets clean from contaminations (Johansson et al. 1998).
- To cool down the process.

The fountain solution normally consists of:

- **Water** – main part in the solution.
- **Alcohol** – usually isopropyl alcohol. Normal amount between 8-12 %. This is used in order to reduce the pH and to lower the surface tension.
- **Wetting agents** – lower the surface tension, usually isopropyl alcohol is used. This creates the thin “film” on the cylinder as required.
- **Plate conditioners** – prevents the acid to act corrosive on the aluminium plates.
- **Gums arabic** – protects the hydrophilic areas from accepting ink.

When mixed in the printing nip the fountain solution and the printing ink form an emulsion. This emulsion may contain up to 50 % of fountain solution (Olsson 1993) depending on the type of substrate (paper porosity and coating), the properties of the plate surface, printing press settings, etc. The fountain solution exists in three different ways of the offset process (Olsson 1993).

- As dispersed water in the ink on the printing areas on the printing plate.
- As free surface water on the printing plate, the blanket cylinder and the ink layers.
- As thick top layers of fountain solution (bulk water) on damp rollers and on non-printing areas on the printing plate.

According to Rosenberg (1984) the bulk water appear in form of drops which is up to 10-50 times larger then the water drops in the emulsion.

The emulsion is not stable, and the equilibrium of the emulsion is dependent on the mechanical work created by the blanket and the impression cylinder. Too high concentrations of fountain solution in the process can create an ink-in-fountain solution emulsion with the result that the emulsion sticks onto the non image areas, leading to decolourisation (Johansson et al. 1998). The equilibrium between the water drops (fountain solution) in the ink and the bulk water is maintained in the printing press. The amount of water drops in the ink increases before and during the printing nip. After the printing nip the amount of water drops in the ink decreases and the equilibrium is restored.

The reason for adding isopropyl alcohol to the water is to reduce the surface tension in order to increase the wettability of the fountain solution on the substrate, see schematic drawing of the wetting procedure in Figure 7. Surface tension is the tangential force that keeps a fluid together at the air/fluid boundary. The wettability of a substance is dependent on its surface roughness and its ability to adsorb vapour (Liiri Brodén et al. 1996).
Figure 7 shows the different stages of a drop of water applied onto a substrate surface, where also isopropyl alcohol is added at a certain stage. The different stages in the Figure 7 are described below.

Stage 1  Start position with clear water, $\Theta = 180^\circ$.
Stage 2  Alcohol is added but the contact angle ($\Theta$) is larger than $90^\circ$ which results in poor wettability.
Stage 3  The contact angle is $90^\circ$, which is in the boundary of good and poor wettability.
Stage 4  Good wettability with a contact angle less that $90^\circ$.
Stage 5  Full wettability $\Theta = 0^\circ$.

![Figure 7: Different stages of the contact angle of a water drop when adding isopropyl alcohol.](image)

Young has developed an equation in order to calculate the surface tension as a function of the wettability angle. The usefulness of the equation is limited, when only two of the parts in the equation, $\cos \Theta$ and the surface tension of the fluid, are directly measurable. Equation 1 is Young’s equation.

$$\gamma_{LV} \cdot \cos \Theta = \gamma_{SV} - \gamma_{SL} \quad [1]$$

Figure 8 shows the different boundary layers between the gas, fluid and the substrate. $\gamma_{VL}$ is the angle that describes the substrates ability to absorb the fluid into the surface. Since Young’s equation is difficult and time demanding to use, different measuring methods based on the equation has been developed.

![Figure 8: The different boundary layers between fluid, gas and substrate.](image)
3.6 Transfer, setting and drying of an offset ink

3.6.1 Transfer of ink

The rheology of the ink and the quality of the substrate are important factors for the transfer of the ink from the blanket cylinder to the substrate. It is for instance necessary that the substrate has a smooth surface and that it absorbs the ink properly in order achieve a high quality print (Liiri Brodén et al. 1996). The ink transfer to the substrate is normally divided into four different steps in the offset process.

1. Compression of the substrate (dependent on the bulk of the substrate and pressure in the nip).
2. Contact between the printing area and the substrate. This is dependent on the surface smoothness and the bulk of the substrate.
3. The setting into the substrate. This controls how deep the components of the ink penetrate into the substrate.
4. The distribution of the ink layer after the printing nip.

Figure 9 shows the printing nip and the corresponding pressure pulse in the printing nip.

![Figure 9. The printing nip with resulting pressure pulse.](image)

Some mathematical equations have been developed to describe the transfer of ink from the blanket cylinder to the substrate. The Walker-Fetsko equation is one of the most common mathematical theories used to describe the ink transfer. Walker and Fetsko believed that the ink transfer is divided into three steps. First the contact between the cylinder and the substrate, then immobilisation of the printing ink on the substrate surface and finally splitting of the free ink film. The Walker-Fetsko equation (Equation 2) describes the amount of printing ink that is transferred to the substrate \(y\) as a function of the amount of ink on the blanket cylinder \(x\).

\[
y = b + f(x - b) \tag{2}
\]

where:

- \(y\) = amount of ink transferred to the substrate (g/m²)
- \(b\) = amount of printing ink immobilised on the surface in the printing nip
- \(x\) = ink film thickness originally on the blanket
- \(f\) = splitting factor, part of the ink transferred to the stock
The Walker-Fetsko equation is also described more schematically in Figure 10.

![Figure 10. A description of the ink transfer to a substrate in a printing nip according to the Walker-Fetsko theory (Olsson 1998).](image)

The Walker-Fetsko equation has been modified by several scientists but is mainly used in its original form (Aspler and Lepoutre 1991). A thesis work performed by Olsson (1998) describes some interesting problems when applying the Walker-Fetsko equation more practically. Olsson found that the W-F equation worked very well on base paper, or uncoated substrate, but when using on coated surfaces the equation gave uncertain results.

As described previously the rheology of the printing ink and the quality of the substrate is important for the ink transfer from the blanket cylinder to the substrate. The ability of the substrate to accept the ink is dependent on the surface tension of the substrate, the ability to accept the right amount of ink, the absorption capacity of the substrate as well as the ability for the applied amount of ink to stay as an ink film, and also the roughness of the substrate (Williams 1988). With low surface roughness, the contact between the substrate surface and the blanket cylinder improves. This results in higher transfer of the printing ink.

Surface tension can affect the ink transfer, especially in four printing processes (Aspler and Lepoutre 1991). A substrates absorption ability of an ink also influences the ink transfer. Substrate with high porosity and compressibility complicate and reduce the absorption of the ink into the substrate (Lindquist 1993), due to the fact that the paper rather decreases its own volume than letting the ink to penetrate.

### 3.6.2 Setting and drying of ink

There are several drying mechanisms that describe the drying of an ink. The drying is often divided into setting and drying of the ink. The setting is often a very fast process while the drying is a slower chemical process. Absorption is the mechanism when the ink setting takes place. The ink vehicle penetrates into the surface or the coating layer and the ink pigment stays more or less on the surface (Liiri Brodén et al. 1996). During the setting phase the concentration of binders in the ink increases and initially the ink tack increases. Figure 11 and 12 show the ink setting on uncoated and coated substrate respectively, before and after drying of ink.
The penetration of the ink vehicle into the surface pores of the coating layer occurs by capillary absorption and leaves the ink particles on the surface of the substrate. This is described by Aspler and Lepoutre (1991) as development of an ink film on a substrate surface. The velocity of the drying process is dependent of the porosity of the substrates, the viscosity of the ink and of the ability of the ink to wet the substrate. To what extent the printing ink wets the substrate is dependent of the chemistry of the ink as well as the characteristics of the substrate (coated or uncoated substrate) (Liiri Brodén et al. 1996).

As mentioned before, offset inks are based on mineral and vegetable oils. The final drying of the ink takes places through an auto-oxidative polymerisation. The oxidation of vegetable oils processes in following steps (Burdall 1993):

1. **Formation of peroxide/hydroperoxide**
   Drying by oxidation occurs when oxygen (O₂) from the atmosphere attacks the active seat on the acid chain in the drying oil.

2. **Disintegration and edification of free radicals**
   The hydro peroxide is decomposed and forms free radicals.

3. **Polymerisation**
   The free radicals react further with a molecule from the drying oil. These addition reactions continue and increase the molecule weight until termination occurs. By increasing the molecule weight the printing ink vehicle transforms to a solid material, which bind the ink pigment and interact with the substrate (Burdall 1993).

4. **Termination**
   The free radicals from step 2 can instead of reacting with molecules in the drying oil, react with each other and terminate the polymerisation.
3.7 Interaction between ink, fountain solution and substrate

The offset printing procedure can be described as the interaction between cohesion and adhesion forces. The cohesion forces are the forces that exist within the fountain solution and the ink layer respectively and want to maintain them. The adhesion force describes how the ink emulsion and the fountain solution adhere to the plate and blanket cylinders as well as the substrate.

The fountain solution that covers the nonprinting areas splits when the ink is applied. Half the layer of the fountain solution stays on the plate cylinder while, the other half follows with the ink application rolls. The condition is that the cohesion forces within the fountain solutions are less than the adhesion forces against the printing ink and the nonprinting areas on the blanket cylinder.

According to Gane and Seyler (1994), the level of tack generated in the ink through phase separation as a function of time will depend on the surface and bulk properties of the porous substrate onto which the ink film is applied. In the study by Gane and Seyler, the printing nip is simplified by eliminating the rolling shear forces in the rotating press, giving the fact that the separation only exists in the plane of the substrate. The contact between the blanket, ink and substrate is then described in three layers, which allows determination of the cohesive and adhesive interactions for each component.

In this study performed by Gane and Seyler, the substrate is a non-porous wettable substrate. *Figure 13* shows the schematic separation of a cylinder and the ink via the cohesive ink film split (a), the ink/coating adhesive failure (b) and finally the blanket/ink adhesive failure (c).

*Figure 13. Cohesion and adhesive forces in a printing nip (Gane and Seyler 1994).*
The adhesion forces are combined with film fracture during the separation, giving continuity of the film breakage. When introducing a porous surface, the film breakage increases due to the increase contact area and its porous structure.

In order to understand the “tack forces” that occurs it is interesting to describe the tack development over a period of time. Figure 14 is a schematic drawing of the cohesion and adhesive forces during ink tack measurement. The curve can be divided into three different segments, the rise time, the max separation force and the surface tack decay.

![Figure 14. The ink tack curve shown in a generalised form. (Gane and Seyler 1994)](image)

The rise time (I) is related to the ability for the coating layer on the substrate to absorb the ink. The micro pores and the wettability of the substrate is a mayor factor to a rapid rise time.

The maximum separation force (II) is a combination of the adhesion of the immobilised ink layer to the coated surface, and the cohesion within the ink in the surface layer as a function of bulk cohesion of the ink layer. The maximum separation force between the coated substrate and the ink reaches a plateau before the ink starts to dry which decrease the tack force.

Surface tack decay (III) is the drying of the ink at longer time scale and is seen as a decrease in absorption of the ink surface on the printing disc. The time taken for this decay to occur is a measure of the total available pore volume for the uptake of the ink fluid.
3.8 Problems during offset printing

Different problems may occur during the printing process. The problems may be related to the printing press itself but the quality of the substrate is of equal importance. In this chapter different print related problems are described.

3.8.1 Picking

Picking problems are usually seen as white spots in the printed areas. Picking problems occur when coated papers are not strong enough to endure the printing conditions such as printing pressure, printing speed and tackiness of the ink. If no loose fibres are present on the surface, the weakest part of the material is probably within the coating layer or at its interface with the base paper. If loose fibres are seen in the picked area then the base paper was the weakest part of the sheet and an improvement in the strength of the base paper would be required.

3.8.2 Delamination

This is related to picking but is only developed on paperboard and laminated sheets. The problem occurs between or within the paperboard layers or in the interface to the coated layer. If the force during the printing process exceeds the strength between and within the paperboard, delamination may occur. A high value of ink tack in the outlet of the offset nip may create a delaminating loading situation on the substrate.

3.8.3 Wet trap

This problem is associated with the effect of fountain solutions on the printed substrate. As the paper goes through the first printing unit the water/fountain solution and the ink will be transferred on to the substrate. If the next unit requires printing on the area that was water damped from the first unit, the fountain solution must either have been sufficiently absorbed into the sheet or lie on the surface where it can be pushed away. If the fountain solution cannot be absorbed sufficiently into the sheet the fountain solution will interfere with the ink transfer from the printing blanket. This will cause a lowering of print density that is referred to as wet trap (ink rejection).

3.8.4 Set-Off

This is an ink-setting problem within sheet fed offset printing that occurs when the printed material has too slow ink setting rate. If the printed ink is not sufficiently dried when the printed sheets are stacked after printing, some of the ink may transfer onto the sheets above. A wet print could also stick to the sheet above within the stack and on separation it may cause rupture of the coating. Some sheet fed offset printers may use anti set-off dust powder and infra red heaters in order to reduce the problem.

3.8.5 Ink piling

This problem may occur when a build up of coating, fibre or ink is set to the blanket cylinder. It occurs when the paper causes a very rapid increase in the tack of the ink because it has a too open structure. A higher level of ink tack will cause greater risk of picking especially at the tail edge (leaving edge of the print) as this area will experience the maximum force. The picked material will be a mixture of coating, fibre and ink and it will be deposited on the blanket cylinder.
3.8.6 Mottle

One print quality related problem is mottle. Print mottle is seen as print density variations from point to point across the surface which is detected to the eye. The different types of mottle that may occur are summarized by Andersson (1999):

- Primary mottle
- Water Interference Mottle (WIM)
- Back Trap mottle (BTM)
- Wet ink Trap Mottle (WTM)

*Primary mottle* is when a substrate is printed only in one nip, with no exposure of back trap or fountain solution. Primary mottle could be substrate related, such as surface roughness, surface structure and porosity, or it can also be related to the substrate ink interaction.

*Water Interference Mottle (WIM)* is caused by the fountain solution interfering with the ink transfer. If the water has been absorbed unevenly from point to point on the substrate it will result in varying amount of ink transferred from the printing blanket to the substrate. The mottle will be seen as variations in print density. A too slow absorption of fountain solution into the paper may also cause *WIM*. This type of mottle requires only a single printing unit and may occur in any ink formulation.

*Backtrap mottle (BTM)* occur mostly in the colour cyan and not in black due to the fact that black is applied with a thicker ink film and slower film setting that cyan. The most important characteristics of *BTM* is that its requires a combination of conditions to occur, that are: more than one printing ink included, a fast setting ink, a fast setting substrate and a non uniform substrate absorption (Plowman Sandreuter 1994).

*Multiple Impressions Mottle or Wet ink Trap Mottle (WTM)* only exists when creating multicolour printing, when several different colours are printed on the same image. This can easily be mistaken for *BTM* caused by inks that are out of proper tack sequence. If the inks are not in the proper tack sequence, and high tack ink is printed over low tack ink, the result will be mottle. *WTM* becomes worse as the number of printing units is increased (Plowman Sandreuter 1984)
4 MATERIALS AND METHODS

In this chapter the materials and methods used in different investigations are presented. All tests were carried out in a laboratory with controlled atmosphere at 23 ± 1 °C and RH 50 ± 2 %.

4.1 Paperboard samples used

Solid bleached board (SBB) from was used in the experimental work. Table 1 lists samples (standard products) used with grammage and surface characteristics. Some of the samples were previously evaluated with respect to mottle tendency and water interference mottle in a full scale printing trial. Some results from this study were used for comparison later in the results.

Table 1. Paperboard samples used in the experimental work.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Board type</th>
<th>Surface characteristics</th>
<th>Reverse side</th>
<th>Grammage g/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board A</td>
<td>SBB</td>
<td>Triple coated, matte</td>
<td>Uncoated</td>
<td>240</td>
</tr>
<tr>
<td>Board B</td>
<td>SBB</td>
<td>Triple coated, high gloss</td>
<td>Single coated, matte</td>
<td>250</td>
</tr>
<tr>
<td>Board C</td>
<td>SBB</td>
<td>Double coated, matte</td>
<td>Double coated, matte</td>
<td>240, 300, 350, 400</td>
</tr>
<tr>
<td>Board D</td>
<td>SBB</td>
<td>Double coated, glossy</td>
<td>Double coated, glossy</td>
<td>240</td>
</tr>
</tbody>
</table>
4.2 Ink tack measurements

The Ink Surface Interaction Tester (ISIT) and the ink tack experimental procedure are described below.

4.2.1 Description of the Ink Surface Interaction Tester (ISIT)

The Ink Surface Interaction Tester (ISIT) consists of a test instrument, an ink distribution unit (IGT) and a computer system, see Figure 15. The instrument is supplied by SeGan Ltd (Perrose, Lostwithiel, Cornwall, UK). The test instrument is controlled by the computer system. The setting of testing parameters and the analysis of the test results are made on the computer.

Figure 15. The Ink Surface Interaction Tester (ISIT).

Figure 16 shows the placement of the test strip on the sample plate and the placement of the tack disc, damp disc and print disc respectively. The pressure force in the nip of damp and ink application is adjustable and marked by P1 and P2 respectively. The test strip is fastened to the sample plate with double adhesive tape (3M, no. 410B).

Figure 16. The placement of different discs and the test strip on the ISIT.
Figure 17 shows schematically the ink tack measurement.

1. The sample plate rotates at a specific printing speed so that an ink film is transferred from the print disc to the paperboard surface. The tack disc is then pressed against the paperboard test strip with the applied ink film, creating an ink-surface interaction.

2. After a specific time, referred to as **hold time**, the tack disc is pulled back and the force required to separate the tack disc from the test strip is recorded as the maximum splitting force. The sample plate and the tack disc are rotated and the test procedure is repeated 12 times, thus, the number of ink tack measurement per test strip is 13.

![Figure 17. Description of ink tack measurement with the ISIT.](image)

The ISIT is specifically designed for measurements of ink tack on a substrate, but can also be used for general printing tests (with or without the measurement of tack). The ISIT is set up for general use with standard offset inks and papers and a minimum of adjustments are necessary for the different tests. The machine parameters on the ISIT that can be adjusted are:

**Print speed (m/s):** Rotating speed of the sample plate to rotate one revolution (360°). Standard setting 0.5 m/s. Range 0.1-1.0 m/s.

**Hold time (s):** The time that the tack disc is pressed against the inked sample. Standard setting 5 seconds. Range 0-10 seconds.

**Delay time (s):** The time between the two ink tack measurements (the time from one ink tack measurement until the tack disc is pressed against the test strip again). Standard setting 15 seconds. Range 1-25 seconds.

**Tack disc:** As default setting, the tack disc was put in a position so that the measurements started at the same position around the periphery every time. However, randomly positioning was also evaluated.

**Pressure P1 (N):** The pressure between the sample plate and the metal disc (damp disc). Standard setting 150 N. Range 0-800 N.

**Pressure P2 (N):** The pressure between the sample plate and the print disc. Standard setting 500 N. Range 0-800 N.
4.2.2 Performance of ink tack measurements

The standard procedure of ink tack measurements is described in a test manual set by the supplier SeGan Ltd.

Test procedure:

1. The paperboard sample is laminated with double adhesive tape on one side and then cut into test strips (25 x 298 cm) in CD.

2. The test strip is fastened onto the sample plate.

3. A standard amount of ink (0.3 ml) is applied with an IGT-ink pipette to the IGT-ink distributor. The ink is distributed on the IGT-ink distributor for 2 minutes in order to achieve a uniform ink film.

4. The print disc is then applied to the distributor for 25 seconds.

5. The print disc is weighed before placed onto the right holder on ink tack tester. The pressure force P2 is connected with the right holder.

6. At a given signal the sample platen rotates with a specific print speed, the test strip and the print disc get in contact and the sample is printed. The standard pressure P2 is normally 500 N but it can be adjusted from 0 N up to 600 N.

7. The tack disc is pressed against the printed test strip during a certain time. The standard hold time is 5 seconds but can be adjusted from 0.5 to 10 seconds.

8. After a certain time (hold time) the tack disc is retracted by a spring with a defined force. The separation force between the tack disc and the inked sample is recorded as a function of time. The maximum level from the force-time curve for each separation is plotted as measured tack force (N).

9. The sample plate rotates as well as the tack disc and the process is repeated 12 times. The standard delay time between measurements is 15 seconds but can be adjusted from 1 to 50 seconds.

10. After the final measurement with the tack disc, the test strip is removed from the sample plate. The print disc is weighed again in order to achieve the amount of ink transferred to the test strip.

11. The IGT inking unit needs to be properly cleaned with petrol and set to dry for a while before applying new ink.
4.3 The pre-damping method

The application of moisture onto the test strip before the printing procedure and ink tack measurements is under investigation by the supplier and can be performed by using one of the following methods.

**Condensation method**

A plain metal disc is cooled down in a refrigerator. At a certain temperature of the disc, the disc is moved from the fridge to the conditioned room. Through condensation a water film develops on the disc surface.

**Volumetric application**

A metal disc with microscopic holes manufactured by engraving is used. The holes are filled with water (or fountain solution) and a doctor blade removes the excess of liquid before applied onto the substrate.

4.3.1 Principle

In this work, the pre-damping procedure only included the condensation method. The reason was that the discs available for the volumetric application were too wide in dimension for our sample plate and did not fit on our instrument. However, the ISIT can be upgraded in order to make this application possible.

The procedure for the temperature measurement and the cooling of the damp disc was developed from different trials. The procedure used is described with pictures in series in Figure 18.

**Test procedure:**

a) The temperature sensor is fastened (glued) onto an isolating material that fits the centre of the damp disc. The display shows the temperature.

b) The isolating material with the sensor is then placed in the centre of the damp disc. The temperature sensor is in contact with the metal on the inside of the damp disc and the isolation material prevents the air from circulating and getting in contact with the sensor. This is important in order to ensure that the temperature shown on the display is the damp disc temperature and not the temperature of the air inside the fridge.

c) The damp disc is placed in a metal box in the fridge. The metal box enables to keep the temperature of the disc when opening the fridge door. The sensor for the fridge temperature is placed free inside the metal box.

d) Before the damp disc is used in any measurement it is placed for a while in a desiccator (the dwell time specified later). This is done in order to be able to get reproductively in the different tests, as the development of the condensation onto the metal disc starts when the disc is placed in a conditioned room. The damp disc temperature will rise a bit in the desiccator but the silica gel prevents any damp to develop.

e) Directly after the removal from the desiccator to the conditioned room a condensed water film will develop on the surface of the damp disc. This film is applied onto the test strip before the printing procedure.
In order to understand the development of condensed water film on the disc, test parameters like
disc temperature, time in desiccator and time for condensation in the conditioned room were
varied between following levels:

**Damp disc temperature**: 4, 6 and 8 °C.

**Dwell time in the desiccator**: 45 seconds and 1 minute 55 seconds (110 seconds).

**Time for condensation in the conditioned room**: 10 and 20 seconds.
4.3.2 Preparation before test procedure

In the manual “Printing test methods” presented by Imerys, the “Offset litho condensed moisture method” is described. This method was considered and somewhat modified in order to suit our own equipments and applications. Here follows a description of the preparation procedure.

The metal disc was cleaned with acetone, and placed carefully in the fridge without touching the outer cylinder area. The temperature sensor and the isolation material were placed in the centre of the metal disc (as shown in Figure 18) and the other temperature sensor next to the metal disc in the refrigerator before closing the door.

When the metal disc had reached the requested temperature (standard setting 6 ± 0.5 °C), the damp disc was placed in the desiccator for 1 minute 55 seconds while preparing the ink disc. After that, the damp disc was placed in the conditioned environment during 10 seconds before run of the test in order to achieve a water film.

4.4 Ink tack measurements with pre-damp

The test procedure was as follows:

1. When the damp disc had reached the requested temperature, the ink distribution was started.

2. The temperature of the surface of the damp disc and the air inside the fridge was noted.

3. After 1 minute of ink distribution the damp disc was taken out from the fridge and put in a desiccator. At the same time the temperature sensor was moved to another damp roll.

4. After a total ink distribution time of two minutes, the print disc was applied to the distributor for 25 seconds.

5. The print disc was then weighed before placed on the right holder on the ink tack tester (P2).

6. When the damp disc had been inside the desiccator for 1 minute 50 seconds, it was placed on the left holder on the ink tack tester (P1 = 150 N).

7. After 5 seconds in the conditioned environment, press OK on the screen to start the measurement.

8. Follow the steps 6-11 in part 4.2.2.
4.5 Laboratory print trials for mottle evaluation

4.5.1 Printing in IGT

Mottle evaluation simulating back trap mottle in the QC laboratory at the Iggesund Mill is performed on paperboard samples printed in the IGT press (IGT-C17). This method is fast and gives a quick indication to the production staff if some process parameters in the production need to be modified in order to reduce the mottle tendency of the paperboard. The printing was performed according to internal standard method (QLABANALYS, Mottling). The mottle evaluation of the printed samples was performed visually using a scale from 1 to 5, where 5 corresponds to a higher level of mottle.

4.5.2 Printing in Prüfbau – Standard procedure

Mottle evaluation with Prüfbau is another method used at Iggesund mill. Figure 19 describes the Prüfbau press used for laboratory print trials. The long red roll in the front of the machine is the inking unit. The damp disc is placed on the left holder and the print disc is placed on the right. The test strip to be printed is fastened onto a rubber sample carrier. The carrier moves from the left to the right, forced under the damp disc and the print disc by rollers. In the standard procedure, no pre-damp was used. When the test strip has been printed, it proceeds through the nip three times in order to simulate back trap in an offset press. The test was performed according to internal standard method (QPULAB, Mottling Prüfbau Offset).

Figure 19. The Prüfbau press.

The mottle evaluation of the Prüfbau printed samples was performed with a scanner based method. The test strips are scanned, and a program, using matlab, calculates the grade of mottle. The program is constructed to measure mottle in full-tone areas printed in cyan. Results are presented as the coefficient of variation within different wavelength ranges, 1-2, 2-4 and 4-8 mm respectively. From these values a model also calculates a mottle number, where a higher mottle number corresponds to a higher degree of mottle.
4.5.3 Printing in Prüfbau with pre-damp

Application of moisture in the Prüfbau print trial was tested in two different ways. At first, we tried to combine two internal standard methods. The water application was performed according to the internal standard method using the fixed damping unit on Prüfbau (QPULAB, Färvgvägran) and the ink application was performed according to internal standard method (QPULAB, Mottling Prüfbau Offset). The moisture was applied as a narrow field while the ink was applied in a broader field so that mottle evaluation with and without pre-damp could be observed on the same strip. The time between the application of water on the test strip and the application of ink was varied in order to find a setting that gave a clear mottle picture. Unfortunately all the results gained in this procedure were not comparable with standard mottle measurement, more likely due to print rejection. The pre-damped area did not get enough of ink applied and one could not see any sign of mottle development as in the case of the area on the test strip that was printed without pre-damp.

Secondly, the condensation method was used for damping procedure. A metal disc from the Prüfbau was cooled down in the refrigerator. The temperature of the damp disc was fixed at 6 ± 0.5 °C. The dwell time in the desiccator and the time for condensation used were according to the setting used in the ISIT measurements, i.e. 110 and 5 seconds respectively. The damping procedure based on condensation was combined with the mottle internal standard method (QPULAB, Mottling Prüfbau Offset).

4.6 Dynamic contact angle measurement

The measurement of the contact angle of a drop of water on a surface is a method to determine the wettability of the liquid on the surface, and the surface ability to absorb the drop. The contact angle can also be related to surface energy. These terms are further explained in section 3.5 in this report. The test method used at the Iggesund mill is performed according to the procedure T-558, and the instrument is a FIBRO 1121 DAT (Dynamic Contact Angle and Absorption Tester).

The measuring principle is such as a drop of a specified volume of fluid is applied onto the paperboard surface. Images of the drop in contact with the substrate surface are captured by a video camera at specified time intervals after deposition. Both the shape and the remaining volume of the drop are registered, and the contact angle as a function of time is received as a result.

4.7 Burn out

Burn out is a method that enables to estimate the evenness of the coating layer on the base paper or base board. A saturated solution of NH₄Cl in 50 % ethanol and 50 % water is applied onto the coated substrate surface, before placed in the oven at 225 °C for 2 minutes. The solution dries on the surface and the result is shown on the test strip as a grey tone. Lighter grey tone indicates a higher amount of coating layer on the base board. The test strip can be scanned, using the same equipment and program as for the Prüfbau mottle samples.

The test was performed according to internal standard method (QPULAB, Burnout).
4.8 Ink rejection
Ink rejection may appear in a multi colour offset printing press, usually in the last printing nip. The printed substrate surface has during the previous printing nips absorbed a mixture of fountain solution and ink. If the substrate is unable to absorb the fountain solution fast enough, the ink is not transferred to the surface properly, and the ink is rejected. In the measurements with pre-damp in Prüfbau printing, there was a tendency to ink rejection on some samples. That is the reason why also ink rejection according to the internal standard method (QPULAB, Färgvägran) was tested as a comparison.

The ink used in this trial was not the recommended one according to the test procedure. The ink that was used was the same ink as used for the mottle test on Prüfbau (described in 4.4.2). This ink was a low tack ink (in accordance with the ink type recommended in the test procedure). The test strips from the test were evaluated in a scale from 1-5, where 5 indicates high ink rejection.

4.9 Description of the performed trials
Following investigations were performed:

**ISIT trials**
- Investigation of testing parameters in ink tack measurements.
  - Ink distribution procedure.
  - Positioning of tack disc and fastening of paperboard sample.
  - Effect of print speed.
  - Effect of print pressure and hold time.
  - Effect of measuring direction (MD or CD).
  - Measurements with different types of ink.

- Ink tack evaluation on Invercote products.

- Inter-comparison between different laboratories measuring ink tack.

- Investigation of the pre-damping method.
  - Effect of temperature on the damp disc.
  - Effect of the dwell time in the desiccator and the condensation time.

- Effect of pre-damp on ink tack measurements.

**Prüfbau trials**
- Mottle evaluation with and without pre damp.
  - Laboratory comparison of samples with different performance.
  - Comparison between laboratory and industrial induced water interference mottle.
5 RESULTS AND DISCUSSION

5.1 Investigation of test parameters in ink tack measurements

In this chapter, the influence of different test parameters on ink tack measurements is presented. This was performed in order to undermine any errors during future tests and to achieve understanding about the measurements. Each presented result is a mean value of 3 measurements if not mentioned. The tack disc was placed in a fixed position, i.e. the first tack measurement started at the same position around the tack disc every time. One exception was a trial where also a random position was evaluated.

5.1.1 Ink application procedure

It is known that the ink application procedure before ink tack measurements differs between different laboratories. The time for ink application onto the print disc from the distribution unit is one parameter that differs.

Figure 20 shows the ink amount on the print disc for two levels of ink application time, 25 and 60 seconds respectively. Each result is a mean value from 5 tests, where the ink distribution unit was cleaned in between every test, and the time for application initially on the distribution unit was 2 minutes.

The ink amount on the print disc was slightly higher when using an ink application time of 25 seconds, comparing to 60 seconds. The coefficients of variation in between the tests were rather low, 4.2 % for 25 seconds and 5.8 % for 60 seconds. In order to speed up the measurements and to reduce the risk that the oil in the ink absorbs into the print units, the shorter time of 25 seconds was used in further experiments.

Figure 20. The ink amount on the print disc for two levels of ink application time.
Another parameter that differs between laboratories is the method for application of ink onto the distributor unit. A test was performed with three different types of application of ink onto the IGT distributor. For each method of application, five ink tack measurements were made on the quality Board A. The different types of application of the ink and the result are shown in Figure 21.

Initially 0.3 ml ink was always applied onto the IGT unit and distributed for 2 minutes before the ink disc was applied to the IGT unit for 25 seconds. For the subsequent tests, the ink application onto the distributor was performed according to following different procedures:

**Case 1)** Cleaning of the IGT distribution unit between every test and application of 0.3 ml ink

**Case 2)** Application of 0.02 ml extra ink in between every test without cleaning

**Case 3)** No extra application of ink and no cleaning of the IGT distributor

![Figure 21. The ink tack for different methods of ink application to the IGT distributor (measurements on Board A).](image)

The ink tack was highest for **Case 1** where cleaning was performed between every measurement. This case also showed a slower ink setting and drying in the later phase of the ink tack measurements. This can be explained by the larger amount of ink transferred to the substrate (1.8 g/m²) and by the fresh composition of ink prolonging the setting and drying of the ink.

In **Case 2** where only 0.02 ml of extra ink is added between every measurement, the curve was similar to **Case 1** initially, but then decreased faster with time. The ink amount was slightly lower (1.7 g/m²), but if the oil tends to absorb into the print units, the ink composition probably changes with time and the ink sets and dries faster.

In **Case 3** where no extra ink was added the ink amount was much lower (1.4 g/m²). The lower ink amount and the reduction of oil in the ink are probably the reasons for the lower tack curve comparing to **Case 1** and 2.
To ensure that the ink composition and the transferred ink amount were as constant as possible, the ink distribution unit was cleaned between every test in further experiments, and 0.3 ml of ink was always applied initially in every test.

The measurements presented in Figure 21 were carried out on an ISIT lent by the supplier initially in the project. This equipment turned out to be unstable during measurements and could not be used continuously in the project. Consequently, these results should be verified in additional experiments.

5.1.2 Positioning of tack disc and fastening of paperboard sample

Different tack discs have previously shown varying ink tack results for the same paperboard quality, probably due to variations within the rubber material between different discs and also around the periphery of one single disc (according to different suppliers and research institutes). In this test two different positionings of the tack disc were investigated, fixed and random positioning. Fixed positioning implies that the ink tack measurement started at the same position every time (a marking was drawn on the edge of the disc at this position).

The way of fastening the test strip onto the sample plate was also investigated. The test strip was fastened with tape under the whole test strip, or by tape only at the edges. Measurements were made on the quality Board A, and the results are shown in Figure 22.

The test presented in Figure 22 was performed according to following alternatives:

*Case 1*) Tape on the whole test strip, tack disc in random position

*Case 2*) Tape on the whole test strip, tack disc in fixed position

*Case 3*) Tape only at the edge of test strip, tack disc in fixed position

![Graph](image-url)

*Figure 22. Ink tack curves for different positionings of the tack disc and different ways of fastening the test strip.*
Comparing the randomly *Case 1* and fixed *Case 2* positioning of tack disc, the two ink tack curves followed each other in the beginning, but diverged in the later part of the curve. This may indicate material variations around the periphery of the tack disc.

In *Case 3*, with tape only at the edges, the ink tack was lower than in *Case 2* where tape under the whole test strip was used. In *Case 3* the total thickness of the sample was lower, probably resulting in somewhat lower pressure in the printing nip when using a constant printing force (P2). The possible difference in printing pressure did not result in a difference within applied ink amount. However, one possible reason to the higher ink tack values for *Case 2* comparing to *Case 3*, could be that the oil is pressed into the substrate due to the higher printing pressure.

Another reason to why lower values are obtained when using tape only at the edges is that the test strip lifts from the sample plate when the tack disc is pulled back to split the ink film. This may create a lower max tack force, or an unstable measurement.

Further tests were performed by using adhesive tape under the whole test strip and by placing the tack disc in the same position in every tack measurement.
5.1.3  Investigation of print speed, print pressure and hold time

The effect of different machine parameters on ink tack measurements was investigated. The different machine parameters and levels used were:

- Print speed (m/s): 0.1, 0.5 and 1.0
- Hold time (s): 1.0 and 5.0 (when tack disc is pressed against printed substrate)
- Force in printing nip, P2 (N): 200 and 600

The supplier recommended following machine parameter set up:
Print speed 0.5 m/s, hold time 5.0 seconds and printing force 500 N.
All measurements were made on the quality Board A.

Effect of varying print speed

Figure 23 shows the effect of different print speeds on ink tack at a hold time of 5 seconds and a printing force of 200 N. When increasing the print speed one decade from 0.1 to 1.0 m/s the whole ink tack curve was lowered and the maximum tack force was reduced from about 7 to 5 N. One explanation to this result may be that an increased print speed reduces the contact time between the substrate and the print disc, which gives the substrate less time to interact with the ink and allowing ink setting on the surface. Hence, increasing print speed results in a smaller amount of ink transferred to the substrate (confirmed by the figures in the diagram), and thereby lower ink tack.

Another explanation for reduced ink tack may be attributed to the thixotropic behaviour of the ink, i.e. that increasing print speed increases the shear rate within the ink film resulting in a breakdown of the ink structure and therefore reduced viscosity. Also note that the time for reaching the maximum tack force appeared to be shorter with increasing printing speed and that the difference in measured tack force is the smallest initially in the curve.

Figure 23. Ink tack versus time at different print speeds. The hold time was 5 seconds and the printing force 200 N.
Effect of varying hold time

Figure 24 shows the effect of varying print speed at two levels of hold time (at constant printing force 200 N). The previous curves from Figure 23 are marked with thick lines, while the new measurement using a reduced hold time of 1 second is drawn with thin lines. The ink tack decreased when decreasing the hold time, and the transferred ink amount still decreased with increasing print speed.

![Figure 24. Ink tack versus time at different print speed and hold time. Hold time 1 second is shown with thin lines and hold time 5 seconds with thick lines. Pressure force = 200 N.](image)

This result was in accordance with previous results obtained in a master thesis work by Keiter (1998). One explanation given in that report was that when the tack disc is pressed against the ink film on the substrate, the internal structure of the ink is destroyed. The shorter the hold time, i.e. the shorter the time for building up the structure again, the lower ink tack is measured. One should note that when using a hold time of 5 seconds instead of 1 second, the x-axis is displaced with 4 seconds per measuring point. The graph in Figure 24 is not compensated to this, so in reality, the ink tack values for hold time 1 second are measured at a lower setting time than what is noted in the graph.
Effect of varying printing force
The effect of varying the printing force between 200 N and 600 N on ink tack was investigated at two levels of hold time (1 and 5 seconds). The print speed was constant at 0.5 m/s. The result of the test is shown in Figure 25.

![Graph showing ink tack versus time at different levels of printing force and hold time. The print speed was constant at 0.5 m/s.](image)

Figure 25. Ink tack versus time at different levels of printing force and hold time. The print speed was constant at 0.5 m/s.

At a hold time of 5 seconds, independent of the printing force level, the ink tack measurements gave the same results (thick lines in the graph). On the other hand, a hold time of 1 second gave a large difference when varying the printing force. In this case, increasing the printing force from 200 N to 600 N decreased the ink tack in general, despite from the first recorded value. One explanation for this reduction in ink tack could be that a higher pressure causes a separation in the ink so that some solvent and oil is pressed into the substrate.

One explanation to the difference in behaviour at different levels of hold time could be that a hold time of 5 seconds enough of time to even out the differences in absorption caused by different printing forces.

Future test were carried out using machine parameter setting recommended by the supplier, i.e. a print speed of 0.5 m/s, a hold time of 5 seconds, and a printing force of 500 N.
5.1.4 Effect of measuring direction (MD or CD)

During ink tack measurements the recommended measurement direction is the cross machine direction (CD). The test results for CD and MD (machine direction) respectively should not differ too much since the high quality demands from customers requires a uniform product which may be printed in either its machine or cross machine direction. Ink tack measurements were performed with two different paperboard qualities (Board A and Board B) in both MD and CD. The results are shown in Figure 26.

![Figure 26. Ink tack measurement of Board A and Board B in MD and CD respectively.](image)

*Figure 26* shows that there was a slight difference between MD and CD in both qualities. Despite from the difference in level, the ink tack curves for respective quality had the same shape for MD and CD respectively. There was no general trend within these results since the MD curve was above the CD curve for the Board A quality, but below in the case of the Board B quality.

One could maybe expect that the board surface is more easily and more evenly wetted by the ink when printed in MD, due to that the topographical roughness (waviness) on the surface often is extended in this direction. This would then result in a faster setting and a lower ink tack curve. Probably, when the surface is very smooth the opposite could also happen. The amount of ink applied on the test strips did not change significantly.

However, in the case of the Board B quality the ink tack curves did not differ too much. Since paperboard may be printed in either MD or CD in industrial application, either direction can be measured as long as the measuring direction is not varied when comparing different qualities. Further measurements were carried out in the CD.
5.1.5 Evaluation of different inks

The composition of ink differs depending on its purpose and placement in a printing press. This test was performed with the aim to evaluate the behaviour of different types of printing ink. Two inks commonly used for laboratory tack tests (cyan and magenta ink) and one industrial printing ink with high viscosity (silver ink) were used and printed onto the quality Board C. Results from the test are shown in Figure 27.

![Figure 27. Ink tack curves for cyan, magenta and silver ink printed on Board C.](image)

The diagram shows that the silver ink gave the highest ink tack. The ink tack increased in the beginning implying a faster ink setting in the beginning than the other two ink types. The ink tack curve then stayed at a steady level over the rest of the measurement period implying a very slow ink drying. There is no obvious explanation to the high level of ink tack in the latter part of the curve. The possible slower drying of the silver ink may be attributed to a slower absorbing oil phase comparing to the other two inks. The pigments in silver inks generally have platy shape, and the amount of pigment in the ink is relatively large. Another explanation for the slower ink drying in the latter part of the curve may be that the absorption of oil into the substrate is hindered by the leafy structure of pigments formed on the surface of the substrate. This high tack behaviour of ink may sometimes cause delamination failure during printing of paperboard.

The two inks commonly used in laboratories had similar performance to each other, although the cyan ink gave the higher ink tack. The amount of ink applied to the test strip was also slightly higher for the cyan ink.

This test was not performed in order to find the perfect ink used for future ink tack measurements, but to show the behaviour of different ink compositions and purposes.
5.2 Ink tack evaluation on Invercote products

Since the different produced qualities have different amount of coating as well as type of coating mixture, a comparison with four different qualities in the same grammage range was performed. Materials used were Board A 240 g/m\(^2\), Board B 250 g/m\(^2\), Board C 240 g/m\(^2\) and Board D 240 g/m\(^2\). The results are shown in Figure 28.

![Figure 28. Ink tack versus time measured on four different qualities.](image-url)

*Figure 28. Ink tack versus time measured on four different qualities.*

*Figure 28 shows that the ink tack differed only slightly between the different qualities. Board A gave a smoother curve than the other three, implying a slower ink setting. The other three qualities reached the max tack earlier in the test, implying a faster absorption of the ink into the coating structure, comparing to Board A. A possible reason for this result is that the coating structure of these qualities contains a larger number of very small pores which would increase the absorption of the ink.*

*Board B, which is the sample with the highest gloss and the lowest surface roughness, had the highest max tack. Despite from the explanation with a larger number of very small pores, this could also be due to a better contact between the tack disc and the sample, because of the smoother surface.*

*The results from this test are that, dependent on the coating structure on the paperboard, the ink penetrates into the coating layer differently. The absorption is for instance dependent on the amount and the sizes of the capillaries in the coating structure.*
5.3 Inter-comparison between different laboratories measuring ink tack

Different ISIT machines from the same supplier, SeGan Ltd, are used in other companies. The aim in this investigation was to see if the results from different machines are comparable to each other.

The same samples used in part 5.2 were sent to Imerys (UK) and STFI (Stockholm) for ink tack evaluation, and compared to our own measurements.

The measurements were done with the same type of ink and the same machine parameter settings in order to make a fair comparison. The only parameter that differed between the different laboratories was the delay time between the measurements.

The results are presented in Figure 29-32, with each quality in a separate diagram evaluated at three different laboratories.

![Figure 29. Ink tack versus time measured on Board A at Iggesund, Imerys and STFI.](image)

![Figure 30. Ink tack versus time measured on Board B at Iggesund, Imerys and STFI.](image)
Figure 31. Ink tack versus time measured on Board D at Iggesund, Imerys and STFI.

Figure 32. Ink tack versus time measured on Board C at Iggesund, Imerys and STFI.

Figure 29-32 all show that the level of the ink tack varies between the laboratories, and that the variation within each quality is about the same. The max tack force measured at STFI was always the highest and when measured at Iggesund, always the lowest. One explanation to this could be that the applied ink amount always was higher at STFI comparing to Iggesund (see figures in the diagrams). However, the ink tack curve obtained from Imerys had a different shape comparing to those obtained from STFI and Iggesund. It took longer time for the max tack value to be reached, and the ink setting appeared to be slower indicated by the flatter gradient of the mid region of the curve. We were told that the type of ink used was the same as used at STFI and Iggesund. However, the difference in shape may be attributed to the fact that the ink was not
from the same batch (as in the case for STFI and Iggesund). Also, there was no data of the applied ink amount achieved from these measurements. The initial ink tack value was very low at Imerys. However, this was due to that the first measurement was made at an earlier stage comparing to at Iggesund and Imerys.

When comparing the different qualities, they were always ranged in the same order, independent of at which laboratory the measurements were performed. This is shown in Figure 33, where all measurements are summarised.

![Figure 33](image.png)

*Figure 33. A summary of Figure 29-32.*

The tests show that even if using the same paperboard samples, the same type of ink and the same parameter setting in measurements on different ISIT machines, the results are not comparable. One factor that may cause the difference in max tack force between the tests is the use of tack disc. The variation within the rubber material on the tack disc has been discussed previously as a factor that can cause variations within ink tack measurements. Also the type of ink, even different batches of the same ink type and the ink amount have big influence on the measurements. This investigation showed that the amount of ink applied is critical and should always be known when performing tests and comparisons.

If future comparisons like this shall be done, the same tack disc should be used in order to avoid differences due to possible material variations between different tack discs. Then tests could help the different laboratories to find a correlation between different ISIT machines.
5.4 Investigation of the pre-damping method

The applications of moisture before ink tack and mottle measurements were done with a cooled down metal disc on which a water film was condensed in room temperature. Different parameters were studied in this investigation: the effect of temperature of the damp disc, the dwell time in the desiccator and the time for condensation before run of the test. The damping and printing procedure was performed with the ISIT, without measurement of ink tack.

5.4.1 Effect of temperature of the damp disc

The different temperatures of the damp disc before it was taken out from the fridge, were, 4, 6 and 8 °C. Two different qualities were used in this investigation, Board A and Board C. The dwell time for the damp disc in the desiccator was one minute and 50 seconds, and the time used for condensation was five seconds in all experiments. The result is presented as the resulting print density on the printed test strip for the different temperatures, and is shown in Figure 34. Each presented value is a mean value of three experiments and for each mean value the standard deviation is shown as error bars.

![Figure 34. The print density on Board A and Board C for different temperatures on the damp disc.](image)

Figure 34 shows that the print density on the printed test strip was dependent on the temperature of the damp disc. Consequently, the amount of water applied to the strip before printing was controlled by the damp disc temperature inside the fridge.

One can expect that, the lower the temperature of the disc, the larger the amount of water that condensates onto the disc in room temperature. Consequently, the amount of ink applied after the damping procedure, and therefore also the print density, should decrease with decreasing temperature of the damp disc. This was also the case for the Board A quality when comparing the different temperatures 4, 6 and 8 °C. When the damp disc was at 4 °C, more water condensed onto the disc and less ink was then applied. However, at 4 °C the damp disc also appeared to be cold and “frosty” compared to the damp disc at 6 °C and 8 °C. This may have caused uneven condensation and hence a somewhat uneven damp and ink application.

For Board C, a temperature at 4 °C gave a larger amount of water applied and hence a lower print density than at 6 °C. However, when increasing the temperature further to 8 °C the print density
was lowered comparing to at 6 °C, which indicates that the transferred amount of water increased. We have no good explanation for this latter result.

The fact that the temperature is measured when the disc still is inside the fridge, and not measured when it is placed inside the desiccator, may be one factor that affect the result. Also, the standard deviation figures show that this procedure is rather uncertain and that the tests are difficult to reproduce.

### 5.4.2 Effect of the dwell time in the desiccator and the time for condensation

An investigation was done in order to see how the dwell time in the desiccator and the time for condensation in a conditioned room affect the amount of water developed on the damp disc and then applied to the test strip. Since the amount of applied water affects the amount of applied ink (where a larger amount of water results in less ink transfer), the tests were evaluated with respect to the resulting ink amount and the print density.

The damp disc was taken out from the fridge at a surface temperature of 6 °C, and was treated in four different ways:

- **Case 1**) 45 seconds in desiccator + 10 seconds for condensation
- **Case 2**) 110 seconds in desiccator + 10 seconds for condensation
- **Case 3**) 0 second in desiccator + 10 seconds for condensation
- **Case 4**) 0 second in desiccator + 20 seconds for condensation

Measurements were performed on Board C 400 g/m² and the result of the test is shown in Figure 35. Each presented value is a mean value of three measurements and for each mean value the standard deviation is shown as error bars. The print density is reported in Figure 35, which is an indication of the amount of ink applied onto the test strip. A high value of the print density indicates a larger amount of ink applied onto the test strip, hence a corresponding smaller amount of water applied in the damping procedure.

![Figure 35](image.png)

*Figure 35. The print density for different cases of preparation within the damping procedure.*
Figure 35 shows that the print density was slightly higher in Case 1 than in Case 2, corresponding to a larger amount of ink transferred. This indicates that a longer dwell time in the desiccator results in a higher amount of water development on the surface of the disc during the subsequent condensation. This result was not expected. One would expect that, the longer the dwell time in the desiccator, the larger the increase of the temperature of the disc during that time, and consequently less water developed during condensation. One explanation to this result may be that some condensation occurs on the disc even though it was placed in the desiccator. Another parameter maybe influencing, is the actual temperature of the disc when it is taken out from the desiccator for condensation. This temperature could not be measured.

In Case 3 and Case 4 the damp disc was not placed in the desiccator at all, but immediately placed in room temperature for either 10 or 20 seconds before printing. In Case 3 where the disc was placed in room temperature for only 10 seconds before printing, a larger amount of ink was applied than in Case 4, where the time for condensation was 20 seconds. This indicates that the longer the damp disc was placed in room temperature for condensation, the higher the amount of water was developed on the surface of the damp disc and transferred to the test strip.

These results show that the dwell time for the damp disc in the desiccator and the time for the damp disc in room temperature for condensation before printing do affect the development of the water film on the damp disc. However, this method seems to be sensitive to these parameters resulting in a variation between different measurements (see the level of standard deviation). A possible way to keep the temperature of the disc and also to improve the reproducibility in the measurements would be to keep the desiccator inside the fridge.

The relation between the print density and the amount of ink applied to the test strip was linear as shown in Figure 36.

Figure 36. The print density versus the amount of ink applied onto the test strip.
5.5 Effect of pre-damp on ink tack measurements

Ink tack measurements were performed both with pre-damp and according to standard procedure (without pre-damp) on four different paperboard qualities. The result for respective quality is shown in Figure 37-40, respectively.

For the Board B quality, the two ink tack curves, with and without pre-damp, followed each other as shown in Figure 37. The ink amount applied to the test strip was also about the same in both cases.

![Figure 37. Ink tack versus time with and without pre-damp.](image)

For the Board A quality the max tack was the same in both cases, see Figure 38. However, the shape of the curves were different. When using pre-damp, the initial tack value on the curve increased, comparing to the case without pre-damp. This result may be attributed to that the applied water film enabled the initial absorption of the ink so that a higher ink tack was reached initially. An explanation may be that the applied water reduced the surface energy of the substrate and therefore increased the absorption, with increased ink tack as a result. The later phase of the curve shows a faster tack decrease when using pre-damp. One explanation for the lower ink tack when using pre-damp application could be that the viscosity of the ink decreases when blended with water. Another could be that the penetration of water into the substrate leads to swelling of the substrate and therefore higher surface roughness. Earlier investigations (Keiter 1998) have shown that increased surface roughness decreases the tack due to poorer contact between the tack disc and the printed sample. The lower level of ink tack in this case may also partly be explained by the slightly lower amount of ink transferred when using pre-damp.
Figure 38. Ink tack versus time with and without pre-damp.

Figure 39 shows that the both ink tack curves for Board D were similar initially. After about 20 seconds of setting time, the curve for the pre-damp trial was lowered, indicating a faster drying of the ink. The transferred ink amount was about the same for both cases. The explanation to this may be the same as given for the measurements presented in Figure 38, despite from the fact that the transferred ink amount was about the same.

Figure 39. Ink tack versus time with and without pre-damp.

Figure 40 shows the ink tack development on Board D, with and without pre-damp respectively. As in the case for Board A, the initial value of ink tack increased when using pre-damp. The behaviour in the later part of the curve was similar to that of Board A and Board D. The lower level of ink tack in this case may also be explained by the slightly lower amount of ink transferred when using pre-damp.
Figure 40. Ink tack versus time with and without pre-damp.

As shown in Figure 37-40, there are only small differences in the results obtained with or without pre-damp during the ink tack measurement. Although rather small differences were obtained between the measurements when using or not using pre-damp, the differences in behaviour in between the different qualities may be due to the difference in coating characteristics.

In Figure 41 the contact angle of a water drop on the surface of respective quality is plotted.

Figure 41. The contact angle for a water drop on the different qualities versus time.

It is common to read the value at 0.5 seconds. At this point, Board B and Board D which both are the glossy qualities had the highest contact angle, 87.8° and 90.8°, respectively. The more matte qualities Board A and Board C, had lower values, 84.2° and 86.6° respectively. The slightly higher contact angle for Board B and Board D should result in a poorer wetting of the applied pre-damp initially, comparing to Board A and Board C. At this stage, we have no clear explanation in the difference in behavior between the glossy and the matte qualities with respect to the ink tack development with pre-damp included.
5.6 Mottle evaluation with and without pre-damp

5.6.1 Laboratory comparison of samples with different performance

Mottle evaluation was performed in laboratory scale using the IGT and the Prüfbau instrument. The printing in IGT was performed without pre-damp while the printing in Prüfbau was performed both with and without pre-damp (all methods are described in section 4.4). The objective in this investigation was to see if there is any difference between mottle tendency when using or not using pre-damp prior to printing in laboratory scale, but also to see if it is possible to separate samples with different performance in industrial printing regarding mottle tendency by using these methods.

Two different samples of Board C 400 g/m² with different performance in printability were printed on the print side and then compared. One sample, referred to as Board C-Trial, had previously shown lower degree of performance with respect to mottle (back trap mottle) in industrial printing. The other sample, referred to as Board C-Reference, appeared to be a good quality reference material taken from the sample room.

During the Prüfbau trials including pre-damp, a modification was done within the damping procedure. In order to simplify the practical handling of the laboratory work, a smaller desiccator than before was used in the condensation procedure during the trials. During the tests it was observed that the amount of applied ink always was higher on the first test strip than on the second and the third. It was also observed that the small desiccator became colder after that the first test had been run. This implies that the temperature inside the desiccator decreased initially in a series of measurements, leading to a lower temperature of the damp disc and thereby probably a higher amount of water transferred to the strip in the second and the third test. Consequently, presented results below are mean values of the second and the third tests performed (excluding the first test in the series).

Table 2 shows different properties evaluated on the two samples that had different performance regarding mottle.

<table>
<thead>
<tr>
<th>Evaluated property</th>
<th>Board C-Trial</th>
<th>Board C-Reference (Better performance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGT mottle (scale 1-5)</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Prüfbau, without pre-damp (scanned value)</td>
<td>4.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Prüfbau, with pre-damp (scanned value)</td>
<td>4.4</td>
<td>4.8</td>
</tr>
<tr>
<td>Visual observation (with respect to mottle with and without pre-damp)</td>
<td>Higher degree of mottle</td>
<td>Lower degree of mottle</td>
</tr>
<tr>
<td>Contact angle (at 0.5 sec)</td>
<td>75.2 °</td>
<td>84.0 °</td>
</tr>
<tr>
<td>Ink rejection (scale 1-5)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Burn out picture</td>
<td>Lower coat amount</td>
<td>Higher coat amount</td>
</tr>
</tbody>
</table>
The printing without pre-damp, both in the IGT and the Prüfbau, resulted in a higher mottle tendency on the Board C-Trial sample than on the Board C-Reference sample. However, the difference between the two samples evaluated in Prüfbau without pre-damp was in reality larger than implied by the mottle values from the scanning of the samples. The Board C-Trial sample had a higher degree of mottle than the Board C-Reference sample. The amount of ink transferred to the samples was the same for the two samples.

The results in Table 2 shows a higher scanned mottle value for the Board C-Reference sample than for the Board C-Trial sample in the Prüfbau test including pre-damp. However, in reality the Board C-Trial sample appeared to have a higher level of mottle, although this was not captured by the scanning. The amount of ink transferred after pre-damp was slightly higher for the Board C-Trial sample than for the Board C-Reference sample and the Board C-Trial sample had a darker tone after printing. This may be attributed to the lower contact angle on the Board C-Trial sample which implies a faster absorption and wetting of this sample. It appeared to be more difficult to compare samples with different mottle tendency when the printed areas on the samples vary in tone. Probably the scanning method also shows limitations in this case. The lower contact angle of the Board C-Trial sample gave a correspondingly lower ink rejection in comparison to the Board C-Reference sample. An explanation to the higher degree of mottle on the Board C-Trial sample may be the lower total coating amount implied by the lighter grey tone of the burn out sample, which probably results in a larger local variation in coat weight over the sample.

A drawback within these experiments was the number of measurements performed, i.e. too few samples were included. Further tests must be performed to really show the usefulness of the different methods when it comes to evaluation of mottle tendency.
5.6.2 Comparison between laboratory and industrial induced water interference mottle

In a previous project, a full scale printing trial was performed in order to investigate the tendency for water interference mottle. Some of the samples evaluated in that trial (Board C 300, 350 and 400 g/m²) were also evaluated in the laboratory using the Prüfbau including pre-damp as a comparison.

The water interference mottle at the full scale trial was created on a certain area on the printing image by adding water in the first three printing nips and printing ink in the last nip. The laboratory printing with pre-damp was performed according to the earlier described method.

Figure 42 shows the scanned mottle values achieved from the laboratory Prüfbau printing including pre-damp versus the water interference mottle values achieved from the full scale printing trial. For these three samples an increasing tendency of water interference mottle in the full scale trial also gave an increased value of mottle in the laboratory evaluation including pre-damp.

Tests were also made on other paperboard products, however, the number of samples were too few in order to draw any conclusions. Further tests on a larger number of samples must be performed in order to see if these methods correlate, and the evaluation of the interference mottle should be made by visual assessments rather than by measurements on scanned samples.

![Figure 42](image-url)

*Figure 42. A comparison between the laboratory mottle evaluation including pre-damp and the water interference mottle evaluated at the full scale printing trial.*
6  CONCLUSIONS

Standard ink tack measurements

- The ink tack measurements were sensitive to the procedure of ink application onto the print disc. A distribution time of 2 minutes on the distributor was used, and the time for ink application onto the disc was 25 seconds. The distribution unit was cleaned in between every test.

- An investigation of the fastening of the test strip onto the sample wheel showed that tape must be applied under the whole test piece, and not only at the edges, to give reliable results.

- The positioning of the tack disc had effect on the ink tack measurements, probably due to variations within the material around the disc. In subsequent measurements the tack disc was positioned so that every measurement started at the same position every time.

- The ink tack decreased with increasing print speed. This result was attributed to the lower amount of ink applied at the higher print speed, but also to the thixotropic behaviour of the ink presumably resulting in a reduced viscosity of the ink at higher print speed.

- The ink tack decreased with decreasing hold time. This result was explained by that a shorter hold time also gives shorter time for the ink film under the tack disc to build up its structure again.

- The ink tack showed different results of the variation of the printing force depending on the level of hold time. Presumably, this result may be attributed to the same explanation as mentioned above.

- There was no general trend in differences between measurements performed in MD and CD respectively. However, tests were subsequently performed in CD according to recommendations from the ISIT supplier.

- Different types of ink were used in ink tack measurements. A silver ink, known as a high tack ink sometimes giving delamination failure in the printing press, gave the highest ink tack and showed a relatively slower ink drying in the latter phase of the measurement. It is important to use the same ink when comparing different substrate qualities. An ink may also vary in properties in between different batches of the same type.

- Paperboard qualities with different coating characteristics showed different ink tack development.

- An inter-comparison between three different laboratories ranged the samples in the same order. However, the maximum and the shape of the ink tack curve differed between the laboratories. The investigation showed that the amount of ink applied is critical and should always be known when performing tests.
Pre-damping method

- The method developed for pre-damp application was based on condensation of a water film on a cooled down metal disc. The water amount developed on the metal disc, and then transferred to the paperboard strip, in general increased with decreasing temperature of the metal disc inside the fridge. A temperature of 5-7 ºC was finally used in further experiments.

- The water amount developed on the metal disc was also dependent on the dwell time inside the desiccator and the time for condensation in a conditioned room. The recommended dwell time and condensation time was 110 and 5 seconds respectively.

- This pre-damp procedure was rather uncertain and the tests were difficult to reproduce.

Ink tack measurements with pre-damp

- The ink tack curve was lowered in the latter phase when using pre-damp, which indicated a faster ink drying. This may be attributed to that the viscosity of the ink decreases when blended with water. Another explanation may be that penetration of water into the substrate leads to swelling and consequently a rougher surface and a lower ink tack.

- In some cases the initial ink tack value was higher when using pre-damp, in comparison to the case without pre-damp. An explanation may be that the applied water reduces the surface energy of the surface and increases the absorption of the ink.

Mottle evaluation with and without pre-damp

- The pre-damp method based on condensation was also used prior to printing in mottle evaluation. Further development is necessary to really see the usefulness of this method and to improve the reproducibility.

- Two paperboard samples with different performance in printing were compared with respect to both water interference mottle and back trap mottle in the laboratory. According to the visual appearance both methods ranged the samples in the same order. Further work must be performed in order to verify these results. Too few samples were analysed.

- Three paperboard samples were evaluated with respect to water interference mottle in both the laboratory and in a full scale printing trial. There was an agreement between the results. However, further measurements and comparisons must be performed to verify the results and to find limitations of the laboratory method.
7 SUGGESTION OF FUTURE WORK

- A broader and more accurate Round Robin test between different laboratories should be performed in order to learn more about why variations in ink tack results with ISIT are obtained.

- Further improvement of the pre-damping method is necessary in order to achieve a better reproducibility in the tests. For instance the thermometer used for measuring the temperature on the disc surface could be a more accurate one, and maybe the temperature shall be measured inside the desiccator as well inside the fridge. A possible way to keep the temperature of the disc and also to improve the reproducibility in the measurements would be to keep the desiccator inside the fridge.

- The volumetric based method for pre-damp application should be tested to see if this method gives better reproducibility than the condensation based method. For this application, investment in volumetric damp discs and probably a rebuilt of the ISIT is necessary.

- After improvement of the pre-damp method, an extended study of the effect of pre-damp on ink tack measurements should be performed. In this study a wider range of coating characteristics may be used and also a larger focus on contact angle and surface energy measurements should be done.

- If the volumetric based pre-damp method may be used in trials, the effect of varying the properties of the fountain solution may be studied (pH, hardness, content).

- An extended study of water interference mottle should be performed in laboratory scale on Prüfbau. A larger range of samples and a larger number of tests must be performed in order to really see the usefulness of this application. Studies could partly be focused on the investigation of the development of water interference mottle due to surface structure of the paperboard, and to local variations in coating layer thickness. Further studies concentrating on the difference in appearance between water interference mottle and general mottle should also be interesting to perform.
8 REFERENCES


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