The Effects of Base Sheet Properties on Blade Forces in Beveled Blade Coating

Derek Denzer
Western Michigan University

Follow this and additional works at: https://scholarworks.wmich.edu/engineer-senior-theses

Part of the Wood Science and Pulp, Paper Technology Commons

Recommended Citation
https://scholarworks.wmich.edu/engineer-senior-theses/107

This Dissertation/Thesis is brought to you for free and open access by the Chemical and Paper Engineering at ScholarWorks at WMU. It has been accepted for inclusion in Paper Engineering Senior Theses by an authorized administrator of ScholarWorks at WMU. For more information, please contact wmu-scholarworks@wmich.edu.
The Effects of Base Sheet Properties on Blade Forces in Beveled Blade Coating

By

DEREK DENZER

A Thesis Submitted
in partial fulfillment of
the course requirements for
The Bachelor of Science Degree

Western Michigan University
Department of Paper and Printing
Kalamazoo, Michigan
April, 1997
Abstract

When coating on a beveled blade coater, the coat weight applied to the base paper is influenced by the doctoring action of the blade. The final coat weight varies as a function of the blade deflection. The blade deflection can be determined by the balance of forces, external and dynamic. The external is the mechanical force applied to the blade, this is also known as the blade loading. The dynamic forces derive from the pressure forces (speed induced), the impulse force (momentum dependent) and finally the hydrodynamic forces. How the roughness of the base sheet affects the blade forces is unknown. By measuring the blade deflection while coating on films with varying roughness, the interaction can be studied under dynamic conditions. Three different films with varying roughness, will be tested under three different blade loading. Experimental measurements of blade deflection will be carried out on a Cylindrical Laboratory Coater, using a position detector mounted on the blade.

There are few conclusions that can be made about the relationship between base sheet roughness and blade deflection. There does not seem to be a correlation between the roughness of the sheet and the deflection of the blade. The reasons for this inconclusive results may be due to the lack inadequate sampling of the amplifier. Because of the problems with the amplifier, the speed of the CLC had to be lowered form 2000 ft/min to 400 ft/min. This lowered speed and lack of needed sensitivity of the amplifier may have introduced error into the results.
Table of Contents

Introduction........................................ 1
Goals and Objectives.......................... 2
Background............................. ............ 3
Methods.............................................. 10
Results and Discussion....................... 16
Conclusions......................................... 27
Recommendations........................... , ... 28
Acknowledgments............................... 29
Introduction

Blade coating is a popular technique for coating paper and paperboard. Pigmented coatings are generally applied for two reasons: to change or improve the appearance and to improve the printability. The popularity of the blade coater stems from its ability to produce smooth, pattern-free coatings at high speeds and a variety of coat weights. Generally speaking, the lower the coat weight, the higher blade forces are required. However, if the blade loading needed to obtain a given coat weight is too large, numerous web breaks, coating defects or blade deposits may occur. To make the blade coating more efficient, the goal is to run at the highest possible solids at maximum speed, without causing runnability problems.

The amount of coating applied by trailing blade coater is generally considered to be related to the base sheet properties, the coating color characteristics, and operating conditions. The blade pressure is the basic mechanism by which coating weight is controlled. Typically coat weight will decrease by increasing the blade load and blade angle. However, it is apparent that the exact mechanisms involved in the blade coating process are not well understood. It is generally accepted that the balance between the color related forces and the deflection of the blade influences the final coat weight. There are several factors that influence the blade deflection such as: base sheet properties, the coating blade, and coating color properties.

There has been a great deal of work on the blade geometry and its effect on the final coat weight, and work is being done now on the effects of viscosity on blade forces (1+2). Therefore, this thesis will focus more on the base sheet properties. The following
are some of the very important base paper qualities that effect coating operations: the sheet roughness, compressibility, and porosity.

These factors are not well understood, but are very important parameters for blade coating. These factors greatly effect the dewatering rate of the coating which in turn affects the cake formation of the color that essentially determines the viscosity and final coat weight. Therefore, the goal of this thesis is to test the effect of base sheet properties on the coat weight in beveled blade coating.
Goals and Objectives

Goals:
The goal for this thesis is to determine the significance of the base sheet properties, in relation to the hydrodynamic forces imparted on the beveled blade coater.

Objectives:
- To prove that base sheet roughness affect the blade deflection by using polyester films with varying surface roughness.
Background

The coating color that is applied to the sheet can be controlled not only by blade pressure, it can be controlled by reducing the solids content. However lower solids reduce the coating quality and increase the energy cost to dry the coating. The higher solids content prevents binder migration into the base sheet (3). Therefore, the solids content in the color is important, but it must also have a good rheology. A good rheology is critical due to the high speeds of the coater. Generally speaking dilatancy, or shear thickening is a phenomenon to be avoided in blade coating color. A coating formulation with dilatant behavior enhances its chances of raising the hydrodynamic pressure to a point where the system becomes unstable (4).

Water retention of a coating color is also a major factor in the runnability of a coating. Excessive water loss to the basestock may cause problems such as blade bleeding, scratches, streaks, web breaks from weakening of the sheet, surface roughening due to fiber swelling and print mottle due do binder migration (5). The coating under pressure tends to move as plug flow into the porous base stock. It likely will penetrate the larger pores and then the tighter porous paper medium, see Fig. 1. Eventually a high solids filter cake will be formed as the interface (6). The extent of water loss, growth of the filter cake, in such a process may vary widely with coating formulations, base stock and sometimes machine settings.

In stiff beveled blade coating, the coat weight applied to the base paper is influenced by the action of the blade. The final coat weight varies as a function of the
deflection of the blade (7). The blade itself can be regarded as a cantilever beam with one end built in by the blade holder and the other end subject to a concentrated load, which depends on the blade pressure (4). Therefore the deflection of the blade is a function of the length of the blade, blade thickness, and the material's modulus of elasticity (2).

As seen in Fig. 2, the coat weight is a function of the blade deflection, or the distance of the between the blade tip and the base sheet. The deflection of the blade is the balance of the forces acting on the blade and the paper. These forces are both external and dynamic (8). The external forces are the mechanical force applied on the blade to regulate coat weight. The tube pressure is used to control blade deformation and loading. The tube pressure is related to the blade force, but the relationship is not obvious and is a function of the contact area between the blade and the tube, the elastic modulus of the tube and the location that the tube contacts the blade (9).

During coating, an excess of coating color is transferred to the base sheet. The coating color strikes against the blade and the excess color is metered by the blade. Some of the coating color passes underneath the blade, giving the final coat weight (2). During this operation three dynamic forces are generated: pressure force, impulse force, and hydrodynamic force.

The pressure force occurs when coating enters the wedge shaped space between the blade and the paper. This space causes local alterations in color velocity. This is a speed induced force. This force is directly proportional to the product of the mass flow rate and the velocity (8).
Figure 1
Effect of base-sheet roughness on Coating

Figure 2
Coating Dewatering Under Blade
The impulse force originates due to the change in the momentum of the excess coating doctored off by the blade. When the excess coating strikes the blade and is metered off, its direction changes. This force is directly proportional to the product of the mass flow rate and the velocity (8).

They hydrodynamic force is generated by the lubrication flow in the channel between the tip of the blade and surface of the paper, the blade nip. As the color enters the nip there is a large velocity difference between the wall and liquid phase (2).

In the actual coating process, under stable operating condition, paper compressibility and roughness represents the weight of coating weight picked up. The sheet roughness is very important parameter for blade coating. It represents the weight of coating that will be removed from the fluid mass in the coating process will instantaneously deposit on the paper surface. Therefore the coat weight is controlled by the surface roughness (10).

During the forming of the coating layer, however, the base paper is compressed beneath the blade tip. This smoothes out the base paper surface. The blade rest on the peaks in the base paper surface and the coating layer is formed by filling the compressed surface volume of the base paper, defined by the blade tip and the topography of the base paper. Typically the mass of coating that has access to the space between the blade and base paper is no more than that available in the big pores. The pores of the paper may also contribute to the faster drainage of the coating, faster formation of the filter cake. The sheet absorbency of the paper will also effect the amounts of coating deposited upon the sheet. Generally the sheet with the greatest absorbency will pick up more coating at constant blade pressure (1). However, the surface roughness changes by the applied
blade force. As paper compresses due to the blade force the surface roughness value will decrease and hence the applied coat weight will decrease.

The higher the sheet absorbency, the greater amount of coating will be picked up. The absorbency of the sheet can be altered by sizing (7). Paper with low sizing picks up more coat weight. The sheet absorbency also effects the surface roughness values. As the swelling of fibers takes place the roughness values increase and more coating is deposited on the paper surface. The sheet porosity is important here to, because the coating pick up is regulated by the displacement of air. Most of the air is displaced through the paper. As machine speeds increase air has to be displaced at a higher rate, therefore the sheet needs to be more porous (2).

The compressibility of the sheet is also important to the coating process. The compression of the sheet can change the blade nip entrance and has a large effect on the forces experienced by the blade (7). The increased force experienced by the blade is caused by the deformation of the paper surface near the blade tip and will result in a small angle between the paper and the blade (11). This will cause an increase of the hydrodynamic force, which will try to lift the blade. The compressed sheet may experience a sponge effect right after the blade. This is due to the recovery of the compressed paper and may result in extra dewatering (6).

All of the base sheet properties directly relate to the dewatering of the coating. The dewatering leads up to an immobilized layer. This layer gives rise to resistance that lowers the impact on dewatering of the pressure pulse generated under the blade (11). However, as the magnitude of the filter cake approaches that of the gap, then the pressure
pulse increases which drives more liquid into the web (3). Therefore the formation of a filter cake is another limiting factor in high speed coating.

These factors are not well understood, but are very important parameters for blade coating. These factors greatly effect the dewatering rate of the coating which in turn effects the cake formation of the color that essentially determines the viscosity and final coat weight. Therefore, the goal of this thesis is to test the effect of base sheet properties on the blade deflection, in beveled blade coating.
Methods

A complete graphical design of the experiment is shown in Figure 3. A delaminated clay coating at 62% solids (15 parts latex addition) was used to coat 3 polyester films. Each film had three different blade run-ins, 20, 30, and 40 in 1000/inch. The three different films were coated using the Cylindrical Laboratory Coater (CLC). In order to reduce other variables that effects coating, such as the sheet porosity, compressibility and many other of the sheet properties, polyester films were used. The roughness of the sheets are classified using the Parker Print Surface test and to calculate the hole volume in the rough sheet an surface image scanner was used. For measuring the deflection, a position detector will be used. The position detector will be mounted on a probe underneath the bond carriage. The actual deflection of the blade will be measured by a position detector (2). During coating any deflection of the blade will cause a displacement in the pin of the probe and voltage signals of the amplifier will be sent to a computer for recording the data.

The coating was a delaminated clay at 62% solids. The color utilized 15 parts of latex, and 100 parts clay. The pH was adjusted to approximately 9 using ammonia. Finally Alcogum, a thickener, was used to achieve a Brookfield viscosity of 1128 cP.

The clamping device was then attached to the block of the pond carriage, Figure 6 and 5. Two wood blocks were inserted into the pond carriage to set the depth of the clamping device. Then rubber padding were placed into the pond carriage under the clamping device. This was done to ensure good contact between the probe and the blade. Then the clamping device was inserted into the pond carriage. Two wooded blocks were
then placed upon the clamping device, to minimize movement for during coating. The clamping device was then adjusted to a vertical position and then tightened down. Then the probe was attached onto the vernier, Figure 6 and 7. The probe was then connected to the amplifier and the corresponding reading was noted. The tip of the probe was then pressed to check the corresponding changes in the reading of the amplifier. The final setup is shown in Figure 8.

The calibration of the setup used one T shaped device, shown in Figure 4. The top portion was clamped to the blade and held with C clamps. Then weights had been hung at the hook and corresponding deflection readings recorded. Readings had been taken for 1, 2, 3, 4, and 5 Kg weights. A sample of the calibration curve is shown in Graph I. Calibrations were done before every run.

After the setup was complete, a substrate without the film attached was coated. This was done to determine the coat path of the CLC. The coat path remained the same as long as the speed of the CLC did not change. Once the coat path was determined, the mylar films were attached to the basesheet. A series of 6 films were taped end to end along the coat path.
FIGURE 3

METHODS

400 ft/min

- CLAY COATING -

- LOW ROUGHNESS -
  - 20-BLADE RUN IN
  - 30-BLADE RUN IN
  - 40-BLADE RUN IN

- MIDDLE ROUGHNESS -
  - 20-BLADE RUN IN
  - 30-BLADE RUN IN
  - 40-BLADE RUN IN

- HIGHEST ROUGHNESS -
  - 20-BLADE RUN IN
  - 30-BLADE RUN IN
  - 40-BLADE RUN IN
Figure 4  Calibration Device

Figure 5  Pond Carriage

Figure 6  Probe Holder

Figure 7  Clamping Device
Figure 8
The CLC Pond with Position Detector
GRAPH 1

CALIBRATION CURVE

Deflection (microns) vs. FORCE (Newton)

\[ R^2 = 0.9649 \]
RESULTS AND DISCUSSION

Base sheet properties.

In order to control the surface roughness of the sheet, polyester films were used. Three films with different roughness values were used in this experiment. After the films were gathered, an accurate measurement of the surface roughness had to be obtained. The first test tried was the Sheffield method, which relates the rate of air flow to the smoothness of the substrate. This reading is typically for the macro-smoothness or the profile of the sheet, which is not sensitive enough for this experiment. Next a Parker print test was used to measure the surface roughness of the sheets, which measures the roughness by an air leakage method. The roughness of the sheets was also obtained from using a stylus profilometer and surface imager from the tribology lab. The results are presented in Table I.

<table>
<thead>
<tr>
<th>FILM ID</th>
<th>SHEFFIELD (SCCM)</th>
<th>PARKER PRINT (µm)</th>
<th>IMAGER (µinch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughest</td>
<td>190</td>
<td>5.8</td>
<td>94</td>
</tr>
<tr>
<td>Matte</td>
<td>20</td>
<td>2.3</td>
<td>368</td>
</tr>
<tr>
<td>Smoothest</td>
<td>10</td>
<td>1.3</td>
<td>140</td>
</tr>
</tbody>
</table>

Note that depending on what test is used, with the larger number being rougher, the samples are not ranked the same. The film that is referred to as the roughest is actually not the roughest with respect to the imager data, this is the Rt term that is in micro-inches, see Appendix I. However this is Believed to be incorrect, due to the fact that the roughness can actually be felt with the fingertips. The data collected does show large pores in the films, however it can not account for the actual texture of the film. The
holes are approximately 50 to 80 micro-inches deep. The data from this test is located in the Film Roughness Appendix I. A stylus profilometer was also used to measure roughness. The test, however was not sensitive enough to get the resolution needed and the integrator was not working so the data was not used in the analysis of the data. However the graphs, in Appendix II, do provide good information when used in conjunction with the other data. The graphs, for the roughest sheet show high peaks and what appears to be the beginning of the pores. The graph for the medium sheet shows a rough surface, however the magnitude of the peaks are smaller than that of the roughest sheet. However, the test used to correlate the roughness of the sheet was the Parker Print test.

**Blade Deflection**

The deflection shown in Figures 2-4, is not an absolute deflection, which means the zero reading for these plots is not the starting position of the blade before loading. After the blade is run into the sheet, the blade position was set to zero. Therefore, the deflection of the blade caused by the loading is eliminated.

For each experimental run, the blade deflection is recorded, as shown in Figures 2-4. Figures 2-4 show blade deflection versus the blade run-ins of the different films. These figures show that the deflection decreased as the blade run-in increased. This may be explained by the higher loading, which is a greater force applied on the blade, which would require more force to deflect the blade. Looking at Figures 2 -4, there seems to be no correlation between blade deflection and surface roughness. It would be expected that the rougher the sheet is, the more it would deflect the blade. This theory is only found
GRAPH 2
BLADE RUN IN: 20

BLADE DEFLECTION VS. SURFACE ROUGHNESS

DEFLECTION

TIME

-10
10
30
50
70
90
110
130
150

Roughest
Medium
Smoothest
GRAPH 3
BLADE RUN IN: 30

BLADE DEFLECTION VS. SURFACE ROUGHNESS
GRAPH 4
BLADE RUN IN: 40

BLADE DEFLECTION VS. SURFACE ROUGHNESS

BLADE DEFLECTION

TIME

Roughest
Middle
Smoothest
for the 40 1000th/inch blade run-in (figure 4). The data represented in Figure 5, blade deflection Vs blade run-in, shows that a trend of the roughest sheet having the highest deflection, followed by the smoothest and then the medium roughness sheet, which are all decreasing as the blade run-ins increase.

Coat weight

As the coating is applied it is metered off by the metering action of the blade, therefore is should be no surprise that as the loading goes up (increased run-in) the coat weight should go down. This trend is shown in Figure 6, but this figure also shows the higher coat weight for the roughest sheet. This too is to be expected due to the fact that the coating will be forced into the holes during coating. The holes in the film have been calculated to have a volume of approximately $4.19 \times 10^{-6} \text{ m}^3$ per one square meter of the sheet. This area, which will hold approximately $6.1 \text{ g/m}^2$ of coating, is enough to explain the increased coat weight. With an increase in the coat weight an increase in the blade deflection should also be observed. This can be explained by the fact that the coating that is not metered off has to travel under the blade, which should increase the deflection. Looking at figure 7, the coat weight seems to have little to no effect on the blade deflection. Even if the coating in the pores is subtracted from the total cotweight, as shown in Figure 8, there can be no correlation seen.

The reasons for these unexpected and inconclusive results may come from inadequate equipment and supplies. When the experiment was planned, approximately 1000 points per second needed to be recorded by the amplifier and computer, what was achieved was about 50 points per second. Due to this, the speed of the CLC had to be
lowered from 2000 ft/min to 400 ft/min. This lowered speed and the lack of needed sensitivity of the amplifier may have introduced error into the results. The speed also needed to be lowered due to the nature of the samples. The samples that would have been best would have been whole rolls of films, instead 8 x 11 inch sheets were obtained.
GRAPH 5

BLADE DEFLECTION VS. BLADE RUN IN

DEFLECTION

BLADE RUN IN

ROUGH
MEDIUM
SMOOTHEST
GRAPH 6

COAT WEIGHT VS. BLADE RUN IN

BLADE RUN IN

COAT WEIGHT

ROUGHNESS
MEDIUM
SMOUEST
COAT WEIGHT VS. DEFLECTION

GRAPH 7

- ROUGH
- MEDIUM
- SMOOHEST

COAT WEIGHT

BLADE DEFLECTION
Conclusions

There are few conclusions that can be made about the relationship between base sheet properties and blade deflection. There does not seem to be a correlation between the roughness of the sheet and the deflection of the blade. However, there is a relation between the blade run-in and the coat weight. The coat weight tends to decrease with an increase with run-in, however this is nothing new. It has been known for quite some time that as the run-in increases the coat weight will decrease. Another trend is, as the blade deflection increases the coat weight also increases. This should be no surprise due to the fact that as the blade deflects there is more room for the coating to pass under the blade.
Recommendations

There is an abundance of work that could be done using the same basic experimental design. If it becomes possible, which would take an adjustment of the integrator to take more readings, this experiment could be repeated using higher CLC speeds. The surface roughness may become more of an issue at higher speeds. Another very interesting experiment would be the effects of coating speeds on the deflection of the blade. If this was done it could be determined at what speed a coating formulation encounters problems. Theoretically, every variable that influences the coating process may be isolated, and the dynamic effects on the blade could be determined.
SPECIAL THANKS TO

Donators:

Robber Weber From Multi Plastics
Glen Van Harken From Rhone-Poulenc
Kathy From Transilwrap
Dave Briere From James River

Assistance From:

Ravi Mohan Joel Kendrick
Wade Rayner Lynn Ly
Alison Berry Nicole Denzer
Emily Denzer

-29-
References


APPENDIX I

Film Roughness

Image data
Title: Roughest

Date: 03/20/97
Time: 11:58:50
Mag: 4.9 X
Size: 368 X 238
Sampling: 0.136 mils
Mode: VSI

Surface Stats:
Rq: 6.727 uin
Ra: 4.921 uin
Rt: 94.468 uin

Terms Removed:
Tilt

Filtering: None
Restore: No
Ref Sub: No
Title: Roughest

Note:

Date: 03/20/97
Time: 11:58:50
Mag: 4.9 X
Size: 368 X 238 pixels
Pixel Size: 0.136 mils
Mode: VSI
Filtering: None
Restore: No
Rt: 94.47 uin

Terms Removed:
Tilt
Normal

Contour

X Plot

3D Plot

Y Plot
Date: 03/20/97
Time: 12:00:16
Mag: 4.9 X
Size: 368 X 238
Sampling: 0.136 mils
Mode: VSI
Surface Stats:
Rq: 18.561 uin
Ra: 14.192 uin
Rt: 368.491 uin
Terms Removed:
Tilt
Filtering: None
Restore: No
Ref Sub: No
Title: Smoothest
Note:

Date: 03/20/97
Time: 12:04:42
Mag: 4.9 X
Size: 368 x 238
Sampling: 0.136 mils
Mode: VSI

Surface Stats:
Rq: 1.693 uin
Ra: 1.010 uin
Rt: 140.015 uin

Terms Removed:
Tilt

Filtering: None
Restore: No
Ref Sub: No
APPENDIX II

Film Roughness

Stylus Profilometer
Roughest

Medium

Smoothest