MECHANICS OF THE BOND

BEST PRACTICES
TWO DIFFERENT BONDS

SF Bond

DB Bond
BONDING VARIABLES

- Starch
- Application
- Paper/Grades
- Heat
- Flute Formation
- Glue Gaps/Curves
- Film Thickness
- Paper Path
- Rider Roll/ Contact Shoes
- Heat Transfer
- Steam Showers
- Moisture Content
- Process Centerlining
- Basis Weight
Heating paper is necessary to form an effective adhesive bond on the corrugator. *Starch, Moisture, Heat, and Pressure* are required for the gelatinization process to occur. Heating the paper is important to the gelatinization process. Overheating the paper will also interfere with the proper bond.

During the corrugating process heat is used to increase the viscosity of the adhesive that has been applied to the tips of the flute tips, by swelling the raw starch. This swelling of the raw starch imparts the initial, or *Green Bonding* (also referred to as tack) between the fluted layer and the facing layer.
BOND PROCESS CONTROL

Quality Bond Window

Not Enough Heat
White Glue Lines
Perfect Bond
Heat
Too Much Heat
Zipperboard
For instance, too much adhesive application requires more heat application. If these extra resources are added to one bond, then they will have to be added to the other bond to keep the board balanced and un-warped.

This excessive amount of adhesive and heat greatly increase the probability of warp, washboarding, poor bonding on the edge, low ECT, and many other board problems.
HEAT TRANSFER

- Affected by operating conditions
  - Width of paper
  - Speed of operation
  - Weight of board
  - Moisture content of paper
  - Amount & type of adhesive.
  - Even contact across the width
  - Even tension across the width
HEAT CONTROL

- How & What do we control?
  - Liner Wrap arms
  - Medium Wrap arms
  - Pressure in the hot plate sections
  - Double facer ballast
    - Combined board temperature and moisture.

SP1 = 42.7°C  SP2 = 63.6°C  SP3 = 42.3°C

Temperature Range  81.8°C – 20.5°C
Flute Tip surface area differences for each, A flute will require more starch than E flute. A flute will then need more heat to gel and cure than E flute.
THE AMOUNT OF STARCH APPLIED DEPENDS ON FLUTE TIP SIZE
STARCH VS. TEMPERATURE AND PAPER:

- How much impact does viscosity, temperature, and paper play in a proper bond?
- Does a larger amount of starch gel quicker than a smaller amount?
- Paper temperature, what role does it play?
STARCH APPLICATION TO FLUTE TIPS
Paper inconsistency will cause a variation in heat distribution.

Too much moisture hinders the heating.

Low moisture facilitates overheating.

“Wet or Dry” Streaks impact temperature variations.

Wet / Dry Streaks > 8” wide
**PAPER EFFECT ON BONDING**

SP1 = 40°C  
SP2 = 27.4°C  

Temperature Range  
43.5°C – 26.3°C
FACTORS THAT IMPACT PENETRATION

- **Starch Viscosity**
  - Based on the starch formula
  - Dependent on temperature (delivery)
- **Paper**
  - Porosity of the corrugated medium and liners
  - Type of paper
    - Virgin
    - Recycled
    - High performance.
  - Moisture % in the sheet
- **Effect paper temperature has on starch**
ADHESIVE VISCOSITY

- Low Viscosity
  - When the adhesive is too thin, or has low viscosity, the water tends to “wick” into the medium. This wicking action may remove the needed water from the glue line, which means the starch may not have enough water to gelatinize completely.

- High Viscosity
  - When the adhesive is too thick (high viscosity), it tends to sit on top of the flute tip, penetrating the medium and glue line very slowly. This will lead to a soft, wet board coming from the corrugator.
Viscosity too Low
Watery Penetrates
Medium too much

Viscosity too High
Does not Penetrate
Starch sits on top
of Medium

Good Viscosity
Good Penetration

Viscosity is the liquid thickness of the adhesive.

- Controlling viscosity is important since it affects the amount of adhesive that is applied to the tips of the flutes, and the rate of penetration into the paper.
WASH-BOARDING/STRIPPING

- Washboarding is caused by the shrinkage of glue in between the liner and fluting during drying.

Washboarding depth is related to amount of glue.
MECHANICS OF THE BOND

- Application
- Wetting/Penetration
- Gelatinization
- Green-Bond
- Drying/ Fully Curing
MECHANICS OF THE BOND

• Bonding terms
• Two types of corrugated bonds.
  • Pressure bonding (SF)
  • Evaporative bonding (DF)
• Green Bond/Wet Tack
MECHANICS OF THE BOND

Liner paper Temperature
82° – 93° C

Medium paper Temperature
71° – 82° C

SF bond

Pressure Bond (SF)

DF bond

The Singleface Bond

Pressure from the pressure roll forces adhesive away from the peak of the flutes to the flanks. Therefore, the bond is weaker since there is less bond at the tips. Not as much paper surface is bonded to the adhesive. There is ungelled starch at the tips of the flutes where the pressure roll forces out the water, which is needed for gelling. This is why we (usually) run about 10 – 15% more adhesive or a different formula at the single-facer station.
**MECHANICS OF THE BOND**

The Doubleface Bond

- Moderate pressure allows bond to form at the flute tips and flanks.
- Less adhesive required since more area is contacted.
- Lower gel point allowable.
- Higher viscosity desired to avoid medium de-watering adhesive before it gets to DF liner.
  - Because of the distance, we run the risk of the medium absorbing too much water from the adhesive. (water is needed for full gelatinization.)

**Evaporative Bond (DF)**

- SF bond
- SF Medium paper Temperature Gel Temp or 10 degrees higher
- DF bond
- Liner paper Temperature 82° – 93° C
Application is the first stage of the adhesive bonding process. The application mechanisms differ for the Singleface liner and the Doubleface liner.

- The application stage relates to the amount of adhesive applied to the tips of the flutes.
- The metering roll clearance (.004” to 0.20”) helps to make a relationship for the amount of adhesive applied. By increasing viscosity, more adhesive (density) will be applied to the flute tips.
- The ability of the metering roll and the glue roll to stay parallel can determine the evenness of the applied adhesive.
MECHANICS OF THE BOND

Flute tip contact with the Applicator roll is important to a proper transfer of starch.
MECHANICS OF THE BOND

Flute tip contact with the Applicator roll is important to a proper transfer of starch.
GLUE GAP SPEED CURVE

Metering – Applicator Glue Gap

Corrugator Line Speed
Evolution of glue roll surface types

Structured (sand-blasted) surface

Matt-finished
Note location of starch line in middle rail
Read thickness from the index value on side of Elcometer
ELCOMETER

Read thickness from the index value on side of Elcometer

Note location of starch line in middle rail
• One practice is to use a stroboscope on flute tips or Applicator roll.
USING STROBE FOR STARCH PLACEMENT
Starch Line is not centered on Flute tip

Starch line on liner not even.
STARCH APPLICATION TO FLUTES AND LINER
PRESSURE ON FLUTE TIP
FLUTE STARCH WIDER THAN LINER
FLUTE CRUSH DURING APPLICATION
POOR PAPER PATH (CLOSE-UP)
POOR PAPER PATH (CLOSE-UP)

- See additional moisture is flute tip.
POOR PAPER PATH (CLOSE-UP)
CORRECT CONTACT SHOE GAP
Notice starch Pick-up trailing edge of Applicator roll

Medium wipe distance
Starch Pick-up leading edge of wipe
STARCH PICK-UP LEADING EDGE OF Wipe
EXAMPLE OF STARCH WIPE & CENTER
Centered on wipe
EXAMPLE OF STARCH WIPE & CENTER

Centered on wipe
Closer look

APPLICATION DEFECTS
Normal Viscosity is at $37.7^\circ$C
So if normal for is 35 sec Stein/Hall at $37.7^\circ$C than at $34.4^\circ$C viscosity would be about 48 seconds. This can have a dramatic impact on viscosity.
Glue line width normal
And centered.
Viscosity appears to be thick and sitting only on tip without penetration.
GLUE LINE ISSUES FROM LOW STARCH DELIVERY TEMPERATURE
Not critical but will be an issue if clean up of starch and resin isn’t resolved. There is some evidence of spotty glue lines and slinging.
GLUE LINES FROM DIRTY CELLS
SLINGING FROM DIRTY STARCH APPLICATOR ROLL
Starch wiped off flute tip at glue machine. Build up of starch at the pan. See next picture.
STARCH BEING WIPED OF FLUTES
STARCH BEING WIPED OF FLUTES
EXCESSIVE FILM THICKNESS  FLOODING
E FLUTE AND HEAVY FILM THICKNESS

Flooded Flute tips, wide Glue Gap. @ Slow Speed
FLOODED FLUTES  HEAVY SOLIDS
THERMO-IMAGING
HEAT CONTROL & MOISTURE MANAGEMENT

- Proper heat level and temperature is critical in determining machine speed and quality of bond.
- As the machine speed in increased or the grade of product increases the heat level demands rise.

SP1=87.2°C
SP2=52.3°C
SP3=44.7°C

SP1=25.1°C
SP2=35°C
SP3=21.3°C
SP4=21.6°C
SPLICER TENSION AND PARALLEL CONCERNS

SP1=68.3°C
SP2=82.3°C
SP3=79.4°C

SP1=87.1°C
SP2=66.3°C
SP3=95.0°C
SP4=86.5°C

Seems at times operators run very low tensions to compensate for wrinkles. This results in loss of heat transfer. When running light weights can be OK. But even heat transfer critical.
UNEVEN PAPER TENSION
MOISTURE SPECIFICATIONS

Moisture remaining in the paper from when it was manufactured also plays an important role in the bonding process. The proper balance is critical.

Too little moisture and the starch will not penetrate the paper, and heat transfer will be greater drying out the paper even more. Too much moisture and the starch will wick away the moisture in the starch. Heat transfer to the paper will be more difficult.

Liner Moisture
Min 6% Max 9%
7% preferred
Variation +/- 1 ½ %

Medium Moisture
Min 7% Max 10%
9% preferred
Variation +/- 1 ½ %
WET STREAK IN ROLL

12 – 13% reading wet streak
Red light means red scale

8.5 -9.5% reading
COLD STREAKS

SP1 = 59.7°C
SP2 = 79.1°C
SP3 = 70.8°C

SP1 = 49.8°C
SP2 = 65.2°C
SP3 = 65.5°C
SP4 = 55°C

Wet Streaks in paper
GREEN ROLLS INVENTORY CONTROL??

SP1=47.1°C
SP2=42.7°C
SP3=33.3°C

SP1=45.2°C
SP2=39.3°C
SP3=33.3°C

SP1=35.5°C
SP2=33.5°C
SP3=30.5°C

SP1=35.5°C
SP2=33.5°C
SP3=30.5°C
Things that cause equipment to get out of alignment
  - Foundation Movement
  - Earthquakes

  - Missed splices
  - Loose fasteners
  - Improper installation
UNEVEN PAPER TENSION

Diagonals indicate uneven paper tension creating wrinkles

Heat transfer will be uneven
UNEVEN PAPER TENSION

Diagonals indicate uneven paper tension creating wrinkles

Heat transfer will be uneven
BRIDGE TEMPERATURE

Management

94.4°C
Bridge Temperature

Management

85.5°C
BRIDGE TEMPERATURE

Management

64.40°C
BRIDGE TEMPERATURE

Management

52.7°C
BRIDGE TEMPERATURE

Management

47.7°C
BRIDGE TEMPERATURE

Management

Temperature dropped from $94.4^\circ C - 47.7^\circ C$

As long as moisture, heat & raw starch are available, gelling continues (raw starch gells until temp. falls below $72.2^\circ C$)

This temperature drop depends on the length of bridge and how much festoon, less festoon less drop. More festoon the larger the drop.
KEYS TO HEAT TRANSFER

• Conventional application
  • Max heat and ballast at first hot plate section
  • Heat tapers off to last plate.

• Typical issues
  • Plate deflection
  • Temperature differential shocks board
  • Poor bonding
  • Warp

Zone 1  Zone 2  Zone 3  Cooling Section

SFW & DFL held together for 8-10 seconds in the doublebacker
DOUBLEBACKER

Zone 1  Zone 2  Zone 3  Cooling Section

Cooler to Hotter

SFW & DFL held together for 8-10 seconds in the doublebacker
HEATING LINER SIDE BUT TAKING TEMPERATURE ON THE FLUTE TIPS

SP1 = 63.1° C
SP2 = 62.0° C

Heated side (Liner), heat must penetrate thorough liner into the medium to the Fluted tip. Flute tip is where starch is applied.
HEAT TRANSFER & MOISTURE MANAGEMENT

Singleface pre-heater

Bottom or Doubleface liner pre-heater

Paper Temp.
A = 82° – 93° C DF Liner
B = 82° – 93° C SF Medium
C = 62° – 68° C Flute tips

* Note for Double-wall add 12° C to settings

Doubleface pre-heater on the doublebacker
HEAT TRANSFER HOT-PLATES

Progressive Jack Shoe Pressure

Post DB temp. Top

Post DB temp. Bottom
• Combine Moisture should be 6%-8% with the target of 7%.
• Set Hot Plate Section for this target.

Liner Moisture  
Min 6% Max 9%  
7% preferred  
Variation +/- 1 ½ %
BOARD QUALITY & OPERATOR CHECKS
WHAT’S IN YOUR KIT?

- IR temperature gun
- K Type Thermocouple
- Digital Heat imaging camera
- Digital Thermometer
- Moisture Tester
- Combined Board Moisture Tester
- Stroboscope
- Film thickness Gauge
- Soak Tank
- Temperature Stick
- Temperature Sensitive heat strips
MEASURING PAPER TEMPERATURES

D:S = 12:1
At focal point

1.5 “ @ 12”
3” @36”
5.3” @60”
STROBOSCOPE FOR FLUTE CRUSH
HEAT SENSITIVE TEST STRIPS.
TYPICAL STARCH WIDTH

- Some typical starch iodine soak widths for:
  - A Flute
    - DF 1.5 mm
    - SF 1.6 mm
  - C Flute
    - DF 1.2 mm
    - SF 1.6 mm
  - B Flute
    - DF 1.2 mm
    - SF 1.2 mm
  - E Flute
    - DF 1 mm
    - SF 1 mm

WPA – WRA will result in heavier glue lines.
STARCH LINER AND MEDIUM MATCH

Starch Line
Flute tip Width
On Medium

Starch Line Width
On Liner
MEASURING GLUE LINE WIDTH

Liner
Starch line

Singleface
Starch line
SF Side –Side Variation
APPLICATOR CELLS BUILD UP STARCH

Not critical but will be an issue if clean up of starch and resin isn’t resolved. There is some evidence of spotty glue lines and slinging.
By Reading the board, you can check for penetration and fiber pull

Proper Temperature will also be evident if you feel the glue line. Too much heat texture will feel like Sandpaper.
BOARD QUALITY & OPERATOR CHECKS
By Reading the board, you can check for penetration and fiber pull

- Center Rip Bond
- Corner Peel
PULL SF @ SHARP ANGLE TO STRESS FLUTE
LACK OF PENETRATION?
DIRECTIONAL PULL
This can be caused by green bond or a brittle bond. Can be eliminated by proper
FIBER PULL VARIATION ??
DE-CAPPING (FLUTE TIP)
QUALITY CHECKS AND TESTS

- Confirm all Temperature Readings side-side
  - Paper
  - Pre-Heaters
- Look for loose edges
  - Wrap arms and paper edges
- Corner peel and center rip tests
- Iodine soak tests
- Combined board moisture tests
Closer look

WARP / BONDING
WARP IS CAUSED BY:

- The Moisture imbalance between liners.
- The Tension imbalance between liners.

*Simply Nothing Else*

Fiber stretch or contraction
Moisture
Plant Humidity – immediate
Plant Humidity – post
Heat
DEFINING WARP

- Warp is either in the machine (MD) or cross direction (CD)
- When is Warp observed
  - Immediately
  - In storage (Post)
- How is Warp Measured.
- We will give an understanding and ways to correct.
WARP MEASUREMENT

- Warp is measured in 1/100 of an inch.
- + is normal or side to side up
- - is reverse or side to side down.
WARP MEASUREMENT

- Automatic Warp detection systems
  - Side to Side detection.
WARP DUE TO MOISTURE IMBALANCE

- 1st.
  - Paper is hydro expansive.
    - As it picks up moisture it will expand.
    - As it loses moisture it will shrink in size.
      - Resulting in a dimensional change in the liners after the bond is made.

- 2nd.
  - The two liners may expand or shrink by different amounts.
  - The mechanical forces created in the board structure results in warp.
  - The degree of shrinkage & expansion is much greater in the CD direction.
EFFECT OF MOISTURE

- When paper absorbs water, the fiber diameter begins to swell. This means that when a liner web becomes wetter, the cross-machine direction of the liner web actually becomes wider.

- If the moisture changes differently on the top side than the bottom side of the combined board, then the combined board will warp.
Strand will expand 15 times its diameter when moisture is applied.

CD direction (Cross Direction)

Will not expand in the MD (Machine Direction)
A Liner Sheet is made up of several ply's or layers of Fiber strands.
FIBERS IN A SHEET

Moisture Applied on the top of sheet

CD

Paper Fibers swollen by moisture

MD

Swollen Fibers Causing Down Warp

Causing the sheet to warp away from the moisture
WARP DUE TO MOISTURE IMBALANCE

SF Liner

5% moisture
From starch

DF Liner

10% moisture
From starch
WARP DUE TO MOISTURE IMBALANCE

SF Liner

5% moisture
From starch

DF Liner

Tension will result from the imbalance of moisture applied to DF liner. Causing down warp.
WARP DUE TO MOISTURE IMBALANCE

- Warp has two stages:
  
  - Stage One - wet phase. When the board is wet, the fibers expand and the board warps away from the moisture.
  
  - Stage Two – Drying phase. When the board dries out it warps to the side that was wet.
THINGS THAT CAUSE MOISTURE IMBALANCE

First Identify source of Moisture

- Starch Application
- Liners Themselves
- Water Sprays
- Coatings
- Heat issues
- Downtime
- Corrugator Belt
THINGS THAT CAUSE MOISTURE IMBALANCE

- Starch Application
- Liners Themselves
- Water Sprays
- Coatings
- Heat issues
- Downtime
- Corrugator Belt

If we add starch past the point of obtaining a good bond then we add excess water. Starch is approximately 75% water, and so excess starch means excess water.
THINGS THAT CAUSE MOISTURE IMBALANCE

- Starch Application
- Liners Themselves
- Water Sprays
- Coatings
- Heat issues
- Downtime
- Corrugator Belt

There should be less than 2% difference between the liners to run flat board. If the difference is greater than 3% we can’t overcome the warp on the machine.
THINGS THAT CAUSE MOISTURE IMBALANCE

- Starch Application
- Liners Themselves
- Water Sprays
- Coatings
- Heat issues
- Downtime
- Corrugator Belt

Paper inconsistency will cause a variation in heat distribution. Too much moisture hinders the heating. Low moisture facilitates overheating.

“Wet or Dry” Streaks impact temperature variations

SP1=60.8°C
SP2=59.4°C
SP3=75.0°C
SP4=90.8°C

Wet / Dry Streaks > 8” wide
WET STREAK IN ROLL

12 – 13% reading wet streak
Red light means red scale

8.5 -9.5% reading
WET STREAK IN ROLL

Wet or Dry streaks can not exceed 8".
Side to Side can not vary more than 2%

Even though the Dovey meter is not a truly a moister meter it does measure variations and widths of variations.

SP1=76.2°C
SP2=97.8°C
SP3=92.3°C
SP4=89.7°C

SP1=69.1°C
SP2=90.8°C
SP3=94.0°C
SP4=97.5°C
COLD STREAKS

SP1 = 87.5°C
SP2 = 79.1°C
SP3 = 70.8°C

SP1 = 49.8°C
SP2 = 65.2°C
SP3 = 65.5°C
SP4 = 55°C

Bad Preheater
THINGS THAT CAUSE MOISTURE IMBALANCE

- Starch Application
- Liners Themselves
- Water Sprays
- Coatings
- Heat issues
- Downtime
- Corrugator Belt

Segmented water sprays were a method to control warp. It was primarily used to control wet-streaks. Modern paper making processes have improved this option should no longer be used to control warp. It disrupts the fiber integrity. (weakens)
THINGS THAT CAUSE MOISTURE IMBALANCE

- Starch Application
- Liners Themselves
- Water Sprays
- Coatings
- Heat issues
- Downtime
- Corrugator Belt

Michelman type of coatings are mostly water and will cause the board to warp.
THINGS THAT CAUSE MOISTURE IMBALANCE

- Starch Application
- Liners Themselves
- Water Sprays
- Coatings
- Heat issues
- Downtime
- Corrugator Belt

Pre-heaters are used to control warp. However, their primary function is to prepare the board for bonding. Can be a major contributor in over-drying the sheet.
THINGS THAT CAUSE MOISTURE IMBALANCE

- Starch Application
- Liners Themselves
- Water Sprays
- Coatings
- Heat issues
- **Downtime**
- Corrugator Belt

When the line is stopped, the board in the hot plate section and on the pre-heaters gets dried out while the Single-facer is left idling. When the line is started back up, the speed difference at which the doublebacker is made as compared to the singlefacer will cause warp.
THINGS THAT CAUSE MOISTURE IMBALANCE

- Starch Application
- Liners Themselves
- Water Sprays
- Coatings
- Heat issues
- Downtime
- Corrugator Belt

Over Steaming or putting water on the belt will cause warp.
TYPES OF WARP

Normal or Up Warp

Reverse or Down Warp

End to End Down Warp

Hook or S-Warp

Twist Warp

End to End Up Warp
EVEN APPLICATION OF STARCH

Starch major source of moisture
• Even Application
• Even Heat
• Even Tension
SUMMARY

- The Cause of Warp is an imbalance in moisture or tension between liners.
- The Types of Warp indicate where the imbalance is.
- Warp can be controlled if we understand how warp takes place.
- In troubleshooting Warp.
  - Look for the Sources of Moisture and Tension.