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Statistical process control - procedures for charting warp

Scope

This Technical Information Paper will concern itself only with statistical techniques used to measure and chart cross directional warp. Because there are no accepted procedures to measure the magnitude of end-to-end, “S,” and twist warp, other statistical techniques must be used to record and chart the presence of these additional types of warp.

Safety precautions

If a paper knife or other cutting tool is used in sample preparation, proper safety precautions must be taken to avoid personal injury from knife cuts.

Content

In cross directional (CD) warp, the line of curvature (warp) moves across the corrugator; that is, the line of curvature is parallel to the flutes. In observing sheets as they are delivered from the corrugator, CD warp can be either “up” (normal) or “down” (reverse). The presence of even a slight amount of CD warp (either “up” or “down”) can cause difficulties with efficiency, speed, and waste control, not only on a corrugator plant's own downstream production equipment, but on box users' automatic case setup, filling, and sealing machinery as well. Misfeeds, jam-ups, slot and print register variation, difficulties with vacuum handling equipment, and reduced operating speeds are typical results if warp is present.

Test methods

The Corrugated Industry Development (CID) group completed a major study in the early 1970s on warp. Warp was defined as a function of sheet width with the result called a warp factor. The formula to determine the warp factor (WF) is as follows:

Formula for measurements expressed in millimeters:

$$WF = (14,650 \times \text{warp}) / (\text{sheet width})^2$$

Formula for measurements expressed in inches:

$$WF = (576 \times \text{warp}) / (\text{sheet width})^2$$

The resulting WF is expressed in decimal form.

The CID group also defined “flat” board as having a WF of equal to or less than 0.25. For definition purposes, up (normal) warp is positive and down (reverse) warp is negative. The nominal definition of flat board is board having 6.4

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mm (0.25 in.) or less warp (either normal or reverse) in a 610-mm (24-in.) sheet. Since the relationship is not linear, the following all have a WF of 0.25:

1.6 mm (1/16 in.)	in	305 mm (12 in.)
6.4 mm (1/4 in.)	in	610 mm (24 in.)
25.4 mm (1 in.)	in	1219 mm (48 in.)
101.6 mm (4 in.)	in	2438 mm (96 in.)

The CID group developed a method to measure warp. A modified copy of the procedure is included as the Appendix. An alternate to the CID “grid overlay” method has been developed consisting of a matrix table with sheet width on the vertical axis and warp on the horizontal axis (Table 1). The WF is determined by finding the intersect point for a particular combination of sheet width and warp. The matrix table is valid for either SI or English units, as long as both measurements (warp and sheet width) are made using the same system.

It should be noted that, when using either the table or the grid overlay method, care must be taken when warp of two different shapes occurs in the same sheet. In these instances, it is necessary to shorten the width of your drawn profile to include only one type of warp (either normal or reverse) and proceed with sheet width and warp measurements as though the actual sheet were only as long as the shortened segment. The effect of this procedure is to more accurately identify localized warp.

Control Charts

Two alternatives are suggested for charting warp.

Method A: Use a conventional $\bar{X}$ and R chart. CID suggests that four locations across the web be monitored for warp. Thus, the subgroup size n becomes 4. With the corrugator in a steady-state condition, and with at least an inch of paper having been run off each roll, samples are collected and warp factors determined for each of the four positions across the web. Suggested sampling procedures are listed following Method B. However, it is recommended that separate charts be kept for each flute. The results are recorded and the average ($\bar{X}$) and range (R) plotted. Figure 1 gives an example of how the chart and work sheet are completed.

This is the standard $\bar{X}$ & R Chart. Anticipated additional uses would be for die cut length variation, caliper score line-up on RSCs, pin adhesion, possibly manufacturer's joint analysis, and many others.

If the proper signs are used (+ = normal, – = reverse), analysis of the $\bar{X}$ data can indicate if the particular corrugator under study has a pronounced tendency to produce a particular direction of warp. Analysis of the R data can point out any cross-machine variation, although a more detailed analysis of the individual data would be necessary to determine any position effect (the tendency of a particular location on the web to nearly always have warp and have it in the same direction). Analysis can be facilitated by always having sample 1 be position A, sample 2 be position B, etc.

Method A has the limitation of always requiring four samples. The $\bar{X}$ and R technique does not lend itself to variable samples sizes. This limitation will reduce the opportunities to take samples.

Method B: Use an X and MR chart. Use the individual and moving range (X and MR) chart and maintain three charts (operator's edge, center, and drive edge) across the machine. Figure 2 shows how this chart and its work sheet are completed.

The operator's edge, center, and drive edge samples from the web are obtained at a frequency from among those suggested below. Warp factors are determined and plotted on the respective position charts. Since we, in effect, have a subgroup of one for each chart, the X and MR chart is used. Analysis of the individual charts can indicate the nature of the “position effect.” Looking at all three charts can indicate any overall machine tendencies. As with the $\bar{X}$ and R charts, separate sets of charts should be kept by flute.

Method B offers the advantage of slightly easier sampling and the automatic highlighting of the “position effect.”

Sampling suggestions

Possible sampling frequencies are as follows:

1. A set of samples for each grade or width change.
2. A set of samples for every roll change.
3. A fixed number of sample sets per shift.
4. Several sample sets per full set of rolls to aid in determining process stability and variability.

At a minimum, the grade, paper width, corrugator speed, date, and time should be recorded for each sample set.

Frequency of sampling is left to the program designer's discretion. It is quite possible that more frequent sampling should be done during the earlier stages of process evaluation, with less required when a stable process has been established.

The several options for sample selection, the corrective action steps outlined in TAPPI's TI Papers on warp and the TAPPI Corrugating Defect Terminology Manual, and the causes for warp outlined in the CID manual combine to suggest several process variables which can contribute to warp. If any of these variables is suspect in causing lack of control in the process, then that variable should be isolated and studied separately. This recommendation would include the study of individual board combinations if analysis of charting by flute suggested that specific grades were a possible cause of warp problems.

Usefulness

Statistical charting has several useful purposes:

1. When a process is initially studied, the charting process and associated notes can indicate causes for out-of-control warp readings. Steps should be taken to eliminate causes for points which are out of the control limits.
2. When a process is in statistical control, management must decide if the process average and estimated standard deviation are acceptable. If not, then management must take steps to change the process average and/or narrow the range of measurement readings (from which the estimated standard deviation is calculated).
3. When a process is in statistical control, with averages and ranges at acceptable levels, then operators must be instructed to investigate all out of limit points and make corrections (if possible). This third use of SPC charting is the actual "control" phase.

Corrective measures

It is not the intent of this TIP to discuss causes and corrective measures. The CID Warp Studies Manual (much of which has been published in the trade journals) is an excellent reference. Additional information on the causes and cures for warp problems can be found in the TAPPI Corrugating Defect Terminology Manual and TAPPI TIP 0304-07 "Warp in Corrugated Board."

Appendix: Warp measurement procedure

This procedure was developed by the Corrugated Industry Development Group. The boldface portions of the text indicate sections which have been added or revised from the original report.

Sampling and sample identification

Sheets are taken from each position across the corrugator as soon as they are delivered by the side delivery conveyor **and stored in a vertical position**. Identify the left-side leading corner of each sheet on the SFL (singleface liner) side of the combined board with:

Position: Use "A," "B," "C," etc., to indicate the position sample was taken from. "A" must always represent the sheet taken from the left side of the corrugator, as viewed from the delivery end of the corrugator.

Time: Mark each sheet with the time of day when the sample was taken.

Trial number: The position “A” sample must always be identified with the trial number (if one is used) and “time.” Other positions need not have the trial number identification as long as “position” and “time” is identified.

Drawing warp profiles

A “warp profile” is drawn with sheets on end with the identification “up and away,” i.e., the DFL (doubleface liner) side is toward you with the trailing edge contacting the profile strip. The profile is traced with a felt tip pen held against the DFL side of the combined board.

The warp profiles should be drawn on white heavy-weight paper or bleached 42 lb liner strips. Cut strips about 10 x 12 in. wide by about 8–9 ft long. Support on a 4 x 8 flat piece of plywood or suitable table.

Trace profiles between time intervals of **5 min** and **10 min** after sheet delivery, i.e., do not start tracing before **5 min** has passed and be finished before **10 min** have elapsed. All “at corrugator” sampling should be done in this manner. If time permits, sample and trace two or three profiles from each position and average the results.

Always use a felt tip pen with a broad rectangular type tip. Use two colors, alternating so that adjacent profiles representing different samplings are of a different color. This makes it easier to record warp factors. Figures 3 and 4 illustrate this procedure.

Warp measurement

All warp values are reported as warp factors. Warp factor represents the inches¹ of warp, in decimal form in a **610-mm** (24-in.) wide sheet. In other words, no matter what the width of the sheet, its warp is reported as if the sheet were **610 mm** (24 in.) wide.

Warp measurement is made by placing a transparent plastic grid over the warp profiles and noting the type and amount of warp present. The grid is marked in **6.4-mm** (1/4-in.) divisions with major marks at **63.5-mm** (2.5-in.) intervals. To simplify measurement and conversion into warp factors, the plastic grid is marked to indicate spans of **305 mm** (12 in.), **432 mm** (17 in.) and **610 mm** (24 in.). For sheets near **432 mm** (17 in.) and **305 mm** (12 in.) in width, double the reading for the **432-mm** (17-in.) span and multiply by 4 for the **305-mm** (12-in.) span to obtain warp factors. Refer to “rule of thumb table” (Fig. 5).

When studying warp, it is desirable to look at four positions across the width of the corrugator. Most corrugators have what is called a position effect, i.e., the operator's side may show up warp most of the time, the next position over (operator center) may show some reverse warp, etc. By determining the predominant type of warp at each of the four positions, it is possible to detect problem areas such as uneven adhesive application, perhaps uneven liner tension over preheaters, etc. Both edges may have some tendency for S warp. This is easily detected with the plastic grid and may be reported by warp factors such as 0.25/0.40R, which would indicate S warp with **6.4 mm** (0.25 in.) of normal warp at the left and **10 mm** (0.40 in.) of reverse warp on the right portion of the sheet. When recording warp factors, *R* placed after the number indicates reverse warp. If *R* is not present, the warp factor indicates normal warp. **The notation + = normal warp and – = reverse warp have been added to facilitate use of warp factors with SPC.**

Keywords

Cross direction, Warpage, Charting, Process control, Statistical methods

¹ Those operating in the SI measurement system will have to consider the warp factors to just be in “units” with $WFL \pm 0.25$ as “good.” No universally agreed upon base line exists to define warp in SI units that compare to the English unit base line of 24 in. Therefore, the matrix chart cannot be recalculated to relate warp into x mm of warp in a y mm sheet.