# Experimental investigation and analytical modeling of cambering process during novel in-site grinding in calendar roll machine

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## Abstract

*The Single and double texture rubber-coated fabrics are manufactured in thousands of meters/day in three roll calendar machines for residential, industrial and commercial applications. Camber in calendar roll machines has a significant role in maintaining the accuracy and quality of the rubber-coated fabrics. In these times in-site grinding processes become more reliable setup for grinding camber on the rollers and eliminating defects in the coated fabrics. This research work primarily focuses on identifying an effective in-site grinding process which discusses the constraints in the usage of process parameters involved, to machine the required camber dimensions on the rolls. A different set of experiments is carried out for eliminating the defects on rolls in a three roll calendar machine. A mathematical model is developed to estimate the optimum material removal rate through the experimental values obtained, for concave and convex camber. It is identified during the validation that the formulated model considering all essential process parameters has a 95 % similarity from the results. This model contributes convinced results to manufacturers for estimating the time, MRR, speed and feed, needed for in-site grinding the cambers with defect elimination.*

**Keywords:** *Calendar rolls, Camber, In-site grinding, Analytical modeling*

## 1. Introduction

The factual calendaring of coated fabrics is the ultimate act of producing rubber-coated fabrics. The methodology is initially blended to produce complete dispersion, then heat to cause calendaring and wound up into rolls., The rubber material is coated on the fabric between the rolls in calendar roll machines and the thickness of coating material depends upon the roll gap and the nip pressure applied between the rolls. The top roll pressure creates a uniform coat of rubber on the fabric, while the bottom roll pressure increases the bond strength between the fabric and the rubber coating. The rolls in the machine is consistently made of cast steel with 18 inches in diameter and 60 inches in length and are mounted at the ends. Due to the size, material and pressure during operation, the rolls get deflect and affect the nip pressure between the rolls[10, 14, 15]. This deflection is compensated with the existence of concave and convex geometry on the rolls called a crown. A crown normally observed on the roll surface is often calculated in few mills (0.001 inches) and the commonly used crown angle is 70° cosine

angle[5]. Camber is achieved on the rolls through a grinding operation. In the conventional grinding method, rollers are disassembled to grinding centers, cambered and then reassembled in the machining center after grinding[3, 16].
Rolls are grinded within the machine and avoid disassembling through the in-site grinding process. In recent times, it is proved that the in-site grinding process eliminates un-balance in rolls, roll handling, transportations, disassembling and installation[2], than the conventional method as shown in Fig. 1. Though the in-site grinding process is recognized as the appropriate method for cambering the rolls without disassembling, the process parameters and implementation involved during grinding are not optimized for effective utilization.

During camber grinding on rolls, the portion of the tool moves in two axes towards the length of the roll and perpendicular to the axis of the roll, to attain the tapered surface in the in-site grinding process. The key parameters involved in grinding conical geometry are workpiece material, feed, cutting speed, time, emery grade and depth of cut, the angle made by the tapered surface concerning the axis of the cylindrical object on the horizontal plane[1, 7, 13].

This work emphasizes the following objectives: (i) to develop a mathematical model for identifying the material removal rate considering all the process parameters during the implementation of the in-site grinding of rolls and (ii) to validate the mathematical model with the experiments performed under determined condition.


**Figure 1. Three roll calendar machine with in-site grinding equipment**

## 2. Material and methods

A three roll heavy duty calendar machine with rolls of 18 inches diameter and 60 inches length is considered for the experiments. Three different trials based on the common errors observed in the rubber-coated fabrics were carried out for this study. Carborundum universal J297 GR r1 fine grade emery cloth is used for grinding. A constant depth of cut of 0.133 mm calculated as per the pitch of feed shaft, obtained in each angular division on the base, is provided as Y-feed. One angular division is incrementally fed during every Y-feed and since there is no variation in the depth of cut, speed of the roller is kept constant for all the trials as 0.1m/s, the normal running speed of the machine during production. Table 1 explains the trials carried out for the corresponding errors. Separate trials were made for thickness variation and web wrinkling errors.

**Table 1. Trials for errors in rubber coated fabric**

| Sl. No. | Trial no. | Errors in coated fabrics |
|---|---|---|
| 1 | Trial 1 | Thickness variation |
| 2 | Trial 2 | Web wrinkling |
| 3 | Trial 3 | Poor adhesion and laminate characteristics |
| 4 | Trial 3 | Torn web |

Thickness variation of the rubber-coated fabric occurs due to the irregular nip pressure between the top and the middle rolls [6, 17]. Variation in the nip pressure is mainly due to improper camber present on the rolls. The middle roll will be a normal plain cylinder without any camber on its circumference and the top roll will have convex camber on its circumference. During the process, the fabric enters from one side through the gap between the middle and the bottom roll as shown in Fig. 2 where the web gets coated on it. Improper camber on the bottom roll surface when it comes in contact with the middle roll creates more pressure at the contact points, leaves no gap for fabric and web to enter, acts as knife and tears the fabric when it passes on that surface [4, 9, 11]. Therefore in Trial 3 when the bottom roll is cambered, poor adhesion and laminate characteristics and torn web errors are eliminated.

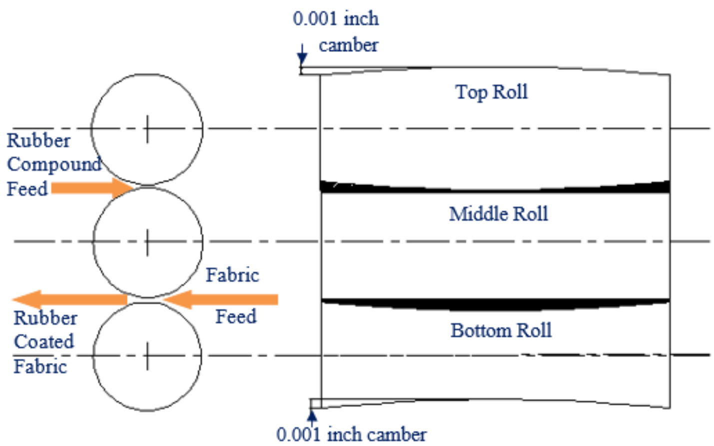


**Figure 2. Rubber compound and fabric feed**

### 2.1 Thickness variation

Top roll is grinded using the in-site grinding equipment, for five hours. Grinding of camber on the top roll is started from the middle of the roll and proceeded to the sides one after the other. Since convex geometry has to be obtained, minimal material grinding is sufficient at the center with one Y-feed and more number of Y-feeds is needed at the ends. Emery cloth in contact with the roll is of 2 inches in width. Therefore one half-length of the roll needs 15 numbers of X-feeds. After grinding the first Y-feed at the middle of the roll, X-feed on any one side is given to grinding the adjacent surface. Two Y-feeds are given to get more depth at the adjacent surface on the roll. Similarly for each X-feed, one Y-feed is increased as indicated in Fig. 3 and the parameters are shown in Table 2. To achieve a camber of 0.001” (23 microns) according to the in-site grinding equipment used, 15 numbers of Y-feeds are needed at the ends of the roll as shown in Fig. 3. Angular divisions on the base of the in-site grinding equipment are used to give the Y-feed through the tightening nut on the feed shaft. After cambering one half of the roller, the same pattern of X and Y feeds are followed on the other half for complete cambering of the roll.

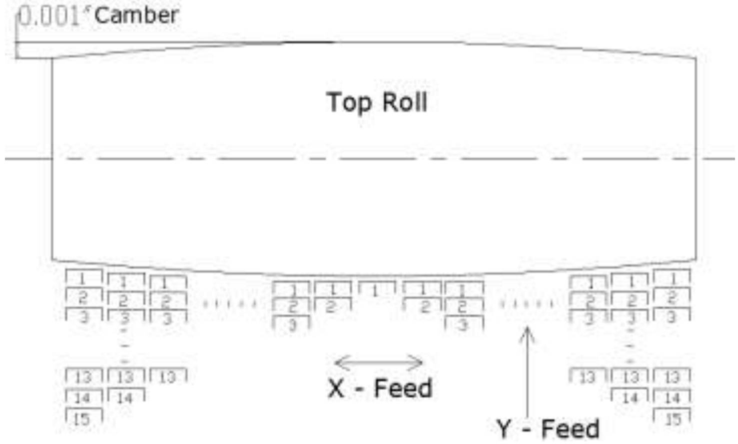


**Figure 3. Top roll with cambering feed indications**

Table 2 shows the values of the process parameters used for grinding the top roll. The process parameters in Table 2 explains that at the end position of a roll, 0” in length, since X feed starts from the middle of the roll, at the end X-feed is 15. In this position of X-feed 15, Y-feed starts from 1 and ends at 15, i.e 15 numbers of feeds are given in the same position as X. The total depth of cut is 2 mm and the time taken for this position alone is 458 seconds.

**Table 2. Process Parameters of Cambering Top Roll**

| Sl. No. | Position on roll in inch (a) | Feed in mm | | | Depth of cut in mm (b) | Time in Sec (c) | Estimated MRR $mm^3$/Sec |
|---|---|---|---|---|---|---|---|
| | | X | Y Start | Y End | | | |
| 1 | 0 | 15 | 1 | 15 | 2 | 458 | 0.601 |
| 2 | 2 | 15 | 1 | 15 | 2 | 458 | 0.597 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | 4 | 14 | 1 | 14 | 1.862 | 419 | 0.598 |
| 4 | 6 | 13 | 1 | 13 | 1.624 | 392 | 0.598 |
| 5 | 8 | 12 | 1 | 12 | 1.48 | 363 | 0.598 |
| 6 | 10 | 11 | 1 | 11 | 1.346 | 329 | 0.594 |
| 7 | 12 | 10 | 1 | 10 | 1.213 | 305 | 0.593 |
| 8 | 14 | 9 | 1 | 9 | 1.080 | 273 | 0.589 |
| 9 | 16 | 8 | 1 | 8 | 0.946 | 242 | 0.585 |
| 10 | 18 | 7 | 1 | 7 | 0.813 | 219 | 0.581 |
| 11 | 20 | 6 | 1 | 6 | 0.801 | 178 | 0.578 |
| 12 | 22 | 5 | 1 | 5 | 0.665 | 154 | 0.578 |
| 13 | 24 | 4 | 1 | 4 | 0.534 | 122 | 0.58 |
| 14 | 26 | 3 | 1 | 3 | 0.400 | 94 | 0.578 |
| 15 | 28 | 2 | 1 | 2 | 0.267 | 63 | 0.577 |
| 16 | 30 | 1 | 1 | 1 | 0.133 | 63 | 0.578 |

Fig. 4 shows the comparison of the camber on the roll measured before and after grinding. A non-uniform camber of 16 microns is grinded into an almost uniform camber of 22 microns. The metal removed during grinding are in the form of fine particles and is carried away by the fluids during the process. As it gets deposited on the emery cloth, cups and base of the grinding equipment, which makes it, very difficult to quantify the exact net metal removed during the in-site grinding process. The volume of metal removed is estimated by identifying the grinded volume of the roll. The gap between the curves indicates the material removed at the corresponding positions of the roll and the volume considered for the corresponding position on the circumference of the roll indicates the volume of the material removed. The above-discussed parameters are further utilized for framing the mathematical equation [8, 12].

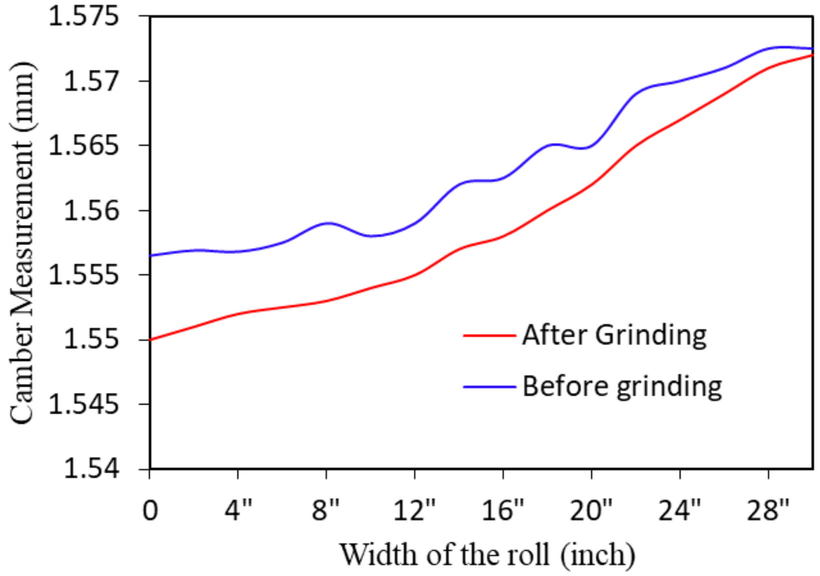


**Figure 4. Camber measurement Comparison - Top roll**

### 2.2 Web Wrinkling

Web wrinkling showed in Fig. 5 in the rubber-coated fabric occurs due to the air entrapment between the fabric and the web content at the gap between the middle roll and the bottom roll during coating. Air present in the pitting of the middle roll is carried along with the web and gets released through the pores in the fabric creating wrinkles in the rubber-coated fabric when compressed between the middle and the bottom roll along with the fabric.

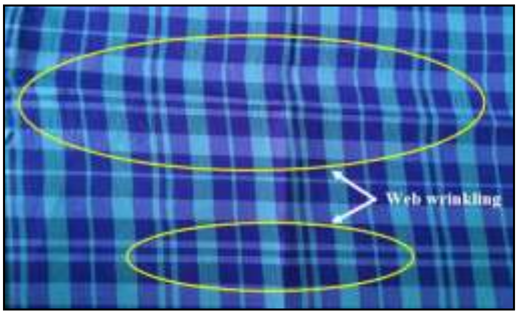


**Figure 5. Web wrinkling in the rubber-coated fabric**

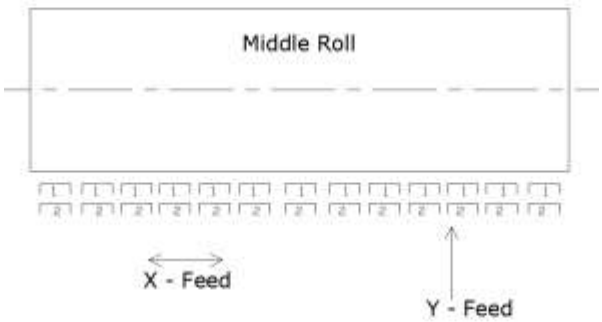


**Figure 6. Middle roll with feed indications**

In trial 2 pitting on the middle roll is removed by grinding. Middle roll geometry is a plain horizontal cylinder and hence the feed for grinding is the same as that of the turning process and shown in Fig. 6. The number of Y feed is based on the depth of the pitting on the roll.

**Table 2 Process Parameters of Cambering Bottom Roll**

| Sl. No. | Position on roll in inch (a) | Feed in mm | | | Depth of cut in mm (b) | Time in Sec (c) | Estimated MRR $mm^3/Sec$ |
|---|---|---|---|---|---|---|---|
| | | X | Y Start | Y End | | | |
| 1 | 0 | 15 | 1 | 1 | 0.133 | 32 | 0.591 |
| 2 | 2 | 14 | 1 | 1 | 0.133 | 32 | 0.593 |
| 3 | 4 | 13 | 1 | 2 | 0.267 | 63 | 0.596 |
| 4 | 6 | 12 | 1 | 3 | 0.400 | 94 | 0.595 |
| 5 | 8 | 11 | 1 | 4 | 0.534 | 122 | 0.592 |
| 6 | 10 | 10 | 1 | 5 | 0.665 | 154 | 0.592 |
| 7 | 12 | 9 | 1 | 6 | 0.801 | 178 | 0.596 |
| 8 | 14 | 8 | 1 | 7 | 0.813 | 219 | 0.596 |
| 9 | 16 | 7 | 1 | 8 | 0.946 | 242 | 0.599 |
| 10 | 18 | 6 | 1 | 9 | 1.080 | 273 | 0.597 |
| 11 | 20 | 5 | 1 | 10 | 1.213 | 305 | 0.598 |
| 12 | 22 | 4 | 1 | 11 | 1.346 | 329 | 0.599 |
| 13 | 24 | 3 | 1 | 12 | 1.48 | 363 | 0.602 |
| 14 | 26 | 2 | 1 | 13 | 1.624 | 392 | 0.608 |
| 15 | 28 | 1 | 1 | 14 | 1.862 | 419 | 0.608 |
| 16 | 30 | 1 | 1 | 15 | 2 | 452 | 0.609 |

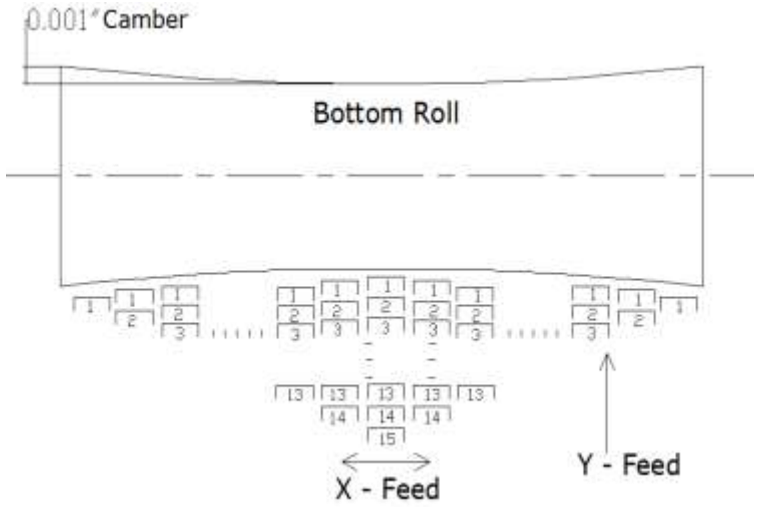


**Figure 7. Bottom roll with cambering feed indications**

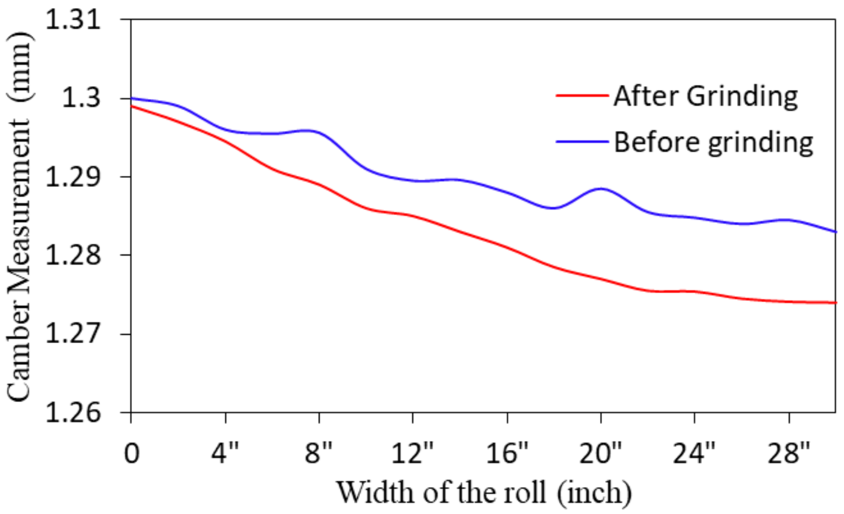


**Figure 8. Camber measurement Comparison - Bottom roll**

As the camber needed is concave, grinding is started at one end of the roll with the feed indication as in Table 3. The feeding process is opposite to the top roll grinding. At positions 14 and 15 in X-feed, one Y feed is sufficient and for subsequent feed in X, an additional Y feed is essential, to achieve concave camber as indicated in Table 3. Camber on the bottom roll is increased from 17 microns to 25 microns and the camber before and after grinding is shown in Fig. 8.

## 3 Results and Discussion

The quantitative behavior of the equipment is calculated by mathematical modeling for concave and convex grinding individually using the data observed during the experiments. A mathematical model for grinding is performed using a matrix method as shown in equation 1.

where 'a' is the feed in mm/sec, 'b' is the depth of cut in mm and 'c' is the time in seconds.

$$\begin{bmatrix} a_2 & b_2 & c_2 \\ a_8 & b_8 & c_8 \\ a_{12} & b_{12} & c_{12} \end{bmatrix} * \begin{bmatrix} Position \\ Depth\ of\ cut \\ Time \end{bmatrix} = \begin{bmatrix} MRR2 \\ MRR8 \\ MRR1 \end{bmatrix} \quad (1)$$

Randomly considering three sets of values from Table 2, position on a roll such as 2, 14 and 22 inches and its corresponding values to obtain the matrix for convex grinding as shown in equation 2.

$$\begin{bmatrix} 50.8 & 2.0 & 458 \\ 50.8 & 1.08 & 273 \\ 50.8 & 0.665 & 154 \end{bmatrix} * \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} 0.597 \\ 0.589 \\ 0.578 \end{bmatrix} \quad (2)$$

From solving equation 2, we get equation 3 representing the mathematical model for the convex grinding process.

$$0.0112a - 0.0269b + 0.00018c = MRR \quad (3)$$

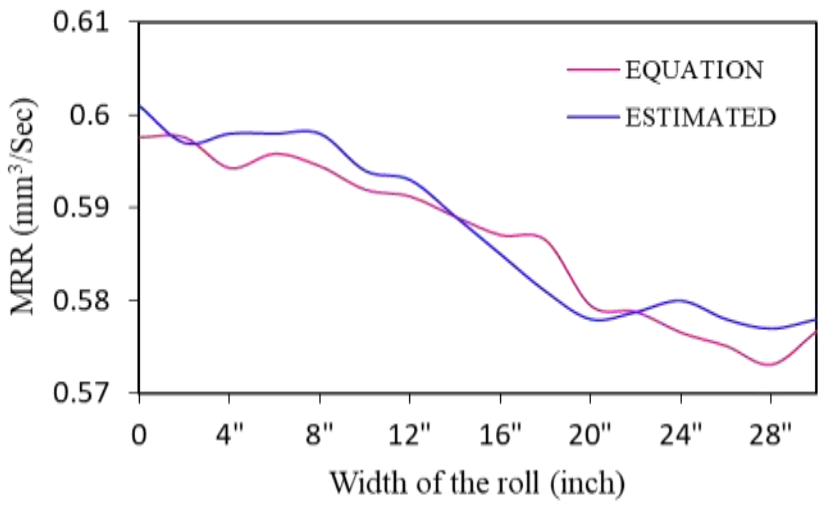


**Figure 9. Comparison of MRR of convex grinding - Top roll**

It is inferred from Fig. 9 that material removed at the ends in convex grinding is more and that in the middle. Similarly, randomly considering three sets of values from Table 3, position on a roll such as 4, 12 and 24 inches and its corresponding values to obtain the matrix for concave grinding as shown in equation 4.

$$\begin{bmatrix} 50.8 & 0.267 & 63 \\ 50.8 & 0.801 & 178 \\ 50.8 & 1.480 & 363 \end{bmatrix} * \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} 0.596 \\ 0.597 \\ 0.602 \end{bmatrix} \quad (4)$$

From solving the equation 4, we get the equation 5 representing the mathematical model for the concave grinding process.

$$0.0117a - 0.0259b + 0.00012c = MRR \quad (5)$$

Fig. 10 shows the graph plotted for the material removal rate of concave grinding concerning the estimated values and the output using equations 3 and 5. Hence, we can predict that the output a value from the equation and it is well established that these equations are in good agreement with the estimated values of MRR is shown in Fig. 10. Hence the equations 3 and 5 can be considered for prediction of MRR during convex and concave grinding of calendar rolls.

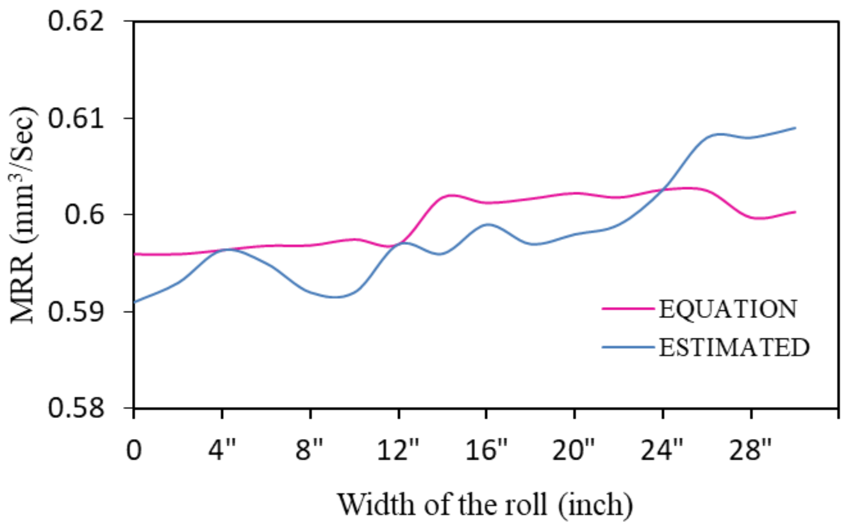


**Figure 10. Comparison of MRR for concave grinding - Bottom roll**

## 4 Conclusions

From the three different sets of experiments, the prevailing errors in calendar roll machines are eliminated and a definite mathematical model is developed to ease implement the in-site grinding process. Based on the results obtained the following conclusions are made:

- Thickness variation in the fabric was eliminated by grinding a proper convex camber on the top roll for 22 microns. An equation for convex camber grinding is developed from the experiments and its results are compared with estimated values. A correlation of 95 % is obtained between the estimated MRR values and the values from the equation. Hence this equation can be used by any manufacturer to estimate the parameters of convex grinding.

$$0.0112a - 0.0269b + 0.00018c = MRR$$

- It is observed during the experiments that the air entrapment in the web is avoided and wrinkles on the rubber-coated fabric are eliminated by grinding the middle roll.
- The characteristics such as adhesion, lamination are improved by grinding concave camber of 25 microns elliptic on the bottom roll and torn web is neglected. An equation for concave grinding is developed from the experiments and the results are validated with the estimated values. A similar to that of the convex equation, the experimental and equation results are in good agreement with 95 % similarity.

$$0.0117a - 0.0259b + 0.00012c = MRR$$

Further research is required to identify the eccentricity variation in camber in the top, middle and bottom roll using sensors and automation for ease identification of deviations in roll dimensions to eliminate the poor-quality products and negative impact on the manufacturer.

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