Product variation improvement and material savings in rubber calendering

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Executive summary

In manufacturing, reducing variation and material waste is imperative for process improvement. We present Six Sigma-driven investigations and findings on product variation and material savings metrics for an EPDM rubber facility.

Through the analysis of quality control data, the study found that tight-tolerance calender roll grinds reduced cross-machine direction thickness variation by 29 percent, with estimated daily material savings valued in excess of $4,000.

Building on the results of this work, we consider future opportunities to investigate roll life extension, calendering of EPDM with a recycled component, and the impact of these grinds on other EPDM product properties.

Introduction

Synthetic elastomers, including isoprene and neoprene, were first developed in the early 1900s (Barron, 1949) to help meet the high demand for natural rubber. Ethylene-propylene-diene-monomer (EPDM) entered the rubber industry in the 1950s and 60s. The material, an M-class rubber, is strong yet pliable, can endure wide temperature extremes, and is resistant to UV radiation, ozone, moisture, acidity and electrical conduction, making it an ideal material for many industries from automotive to construction.

TECHNICAL NOTEBOOK
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EPDM can be formed with most plastic processes, including calendering, compression molding, injection molding and extrusion. Calendering EPDM material typically produces product with greater tensile strength than other common elastomer manufacturing processes such as compression molding (Song et al., 2020) and extrusion. Built on the established calendering practices for paper, metal and textiles, calendering for rubber uses a method where a supply of elastomer from an extruder is squeezed into the nip or gap between two long counter-rotating cylindrical rolls, pressing the product into thin sheets (Cheremisinoff, 2001). The journals of the rolls rotate in hard-wearing frames usually capable of adjusting the nip separation, and the calender rolls themselves are typically heated for elastomer applications. When rolls wear over time, they are reground to restore the necessary shape. Deviations from round can introduce variability in the final material produced, so running calenders with undamaged, precise grinds is necessary for optimal product consistency (Rosato et al. 2004; Crawford, 1998).

The facility that is the subject of this study calenders sheets of EPDM rubber. The facility had difficulty in maintaining consistent thickness along the cross-machine direction of the material; this variation had led to difficulty during the end use of the product. During processing at this EPDM facility, the elastomer travels through four calender rolls. The facility completed a review of their process and found the root cause of the variation to be these calender rolls. The geometric tolerances of the rolls were significantly out of specification, and it was concluded that they needed to be refurbished with a regrind. A quality roll service would ensure that the roll profiles had no deviations larger than 0.0002 inch. (This specification is dependent on the situation; in other applications, far tighter tolerances may be required to achieve a more uniform profile.) A Six Sigma-driven analysis was undertaken to study the impact on the facility's rubber calendering performance. The objectives of this EPDM calendering study were to quantify improvements in cross direction gauge thickness variation as well as to quantify the potential material savings from variation reduction.

Methodology and analysis

The four calender rolls were reground in two sets of two rolls each. Initially, the first set of two rolls was serviced and reinstalled. The facility saw immediate improvement, but there was still residual variation present. The second set of two calender rolls then was serviced and reinstalled. Further variation reduction and resulting product quality increases were immediately evident.

This facility produces multiple thicknesses of EPDM; one thickness that accounts for a large percentage of production, 60-gauge, was chosen as the main product to analyze. Product thickness measurements were recorded manually at 22 locations across the width of the EPDM sheet. The data collection for this study spanned across five years and examined the product prior to any roll grinds, after the first set of grinds, and after all grinds were completed in order to quantify how much improvement had been made in each step of the process.

In the analysis, the 60-gauge EPDM data was first separated from that of the other grades, and any extreme outliers that indicated data entry mistakes were removed. The 60-gauge data then was separated into the three time periods: "before roll changes," "2 rolls changed" and "4 rolls changed." During the course of each time period, the profile of the sheet had been measured hundreds of times at each of the 22 stations on the cross direction. The mean of the data collected from each station was calculated and used to represent the average thickness of the sheet at that location. These points produced a representative product profile of the EPDM material for that time period (**Figs. 1-3**). The facility's lower specification limit (LSL) for the product is included on the plots.

After constructing product profiles from the means of the

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data collected at the stations, roll profile information was gathered, and the deviations from the nominal shape were noted. The roll shape deviation values for all four rolls at each cross direction station were summed up so that the net impact of the cross direction roll profiles on the product could be considered. After summing up the profiles of the rolls, the standard deviations of the roll profile deviations from nominal were calculated for all three time periods and are tabulated in **Table 1**.

In order to investigate the changes in cross directional product variation, the mean standard deviation value for product thickness from each time period was calculated with the software Minitab (Minitab L.L.C., 2021). Minitab's Row statistics function was used to calculate the standard deviation for each of the cross direction samples, resulting in one standard deviation value for each time a 22-station measurement was collected. The mean of these standard deviation values was calculated for each time period. The resulting cross direction standard deviation values can be seen in **Table 1**, showing a 12-percent reduction in variation after the two calender rolls were ground and a 29-percent improvement after all four rolls were ground.

A review of the changes in product profile variation found that, as expected, there was a strong relationship between the EPDM averaged profiles and the profile shape deviation of the calender rolls that produced them. When the roll profiles had more deviation from their target shapes, there was a corresponding increase in product thickness variation. This relationship is illustrated in **Figs. 4-6**. In **Fig. 4**, prior to any precision calendar grinds, the calendar roll profiles are non-uniform and product quality suffers from thick and thin spots. In **Fig. 5**, all calendar rolls have been ground to tight tolerances and the resulting EPDM profile is significantly more controlled.

An initial Minitab regression model compared the cross direction product profile with the cumulation of the four roll profiles. The model indicated that when none of the rolls had been ground to precision tolerances, approximately half (51.84 percent) of the product variation could be attributed to the imperfections in the roll profile (**Table 1**). After the first two rolls had been ground, the regression model attributed 24.72 percent of the product variation to the roll profile variation. After all four rolls had been ground to precision tolerances, the model found that only 5 percent of the remaining variation could still be attributable to the roll profiles. The initial conclusion from this analysis was that a significant portion of the starting variation in the product thickness was due to the roll profiles, and that this variation could be minimized by grinding the rolls to precision tolerances. The work done on this regression model was intended to be an initial overview model only, and more work is needed.

After confirming the statistical connection between the improved roll profiles and the reduction in product variation, the study attempted to investigate the potential material savings available to the facility. The improvements in thickness variation imply an opportunity for a process adjustment that could produce a reduction in material usage. Since the sheet thickness became consistent along the cross direction without high or low points, the EPDM sheet could be made with less material, without the risk of a portion of the product being too thin for specification limits. To quantify the opportunity for waste reduction and material savings resulting from the more consistent sheet gauge thickness, a Monte Carlo simulation (Harrison, 2010) was deemed the best solution to approximate the amount of material used at different steps of the process. As the amount of production between manual gauge thickness measurements was not known, it was not possible to estimate material savings from the dataset alone. The parameters and explanation for each factor in the Monte Carlo simulation are seen in percent.

The simulated data was created using Minitab's Calc → Random data → Normal Distribution. A 10,000-foot simulated total length was studied in 10-foot simulated sections. The sheet width of the 60-gauge EPDM product analyzed varies, but its average width is 121.7 inches. Each 10-foot x 121.7-inch simulated section was divided into 22 components of varying thicknesses, calculated using the means and standard deviations from the data set of the 22 station measurements across the width of the EPDM sheet. Once the Monte Carlo simulated data was created for both the before roll changes and 4 rolls changed time periods, the volume of each 22-section 10-feet x 121.7-inch component with-

Fig. 1: Product profile – before roll changes.

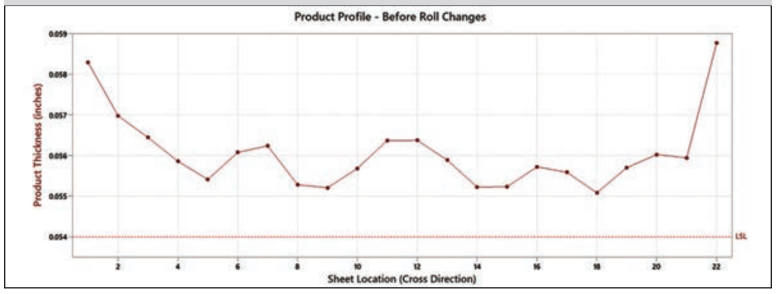


Fig. 2: Product profile – 2 rolls changed.

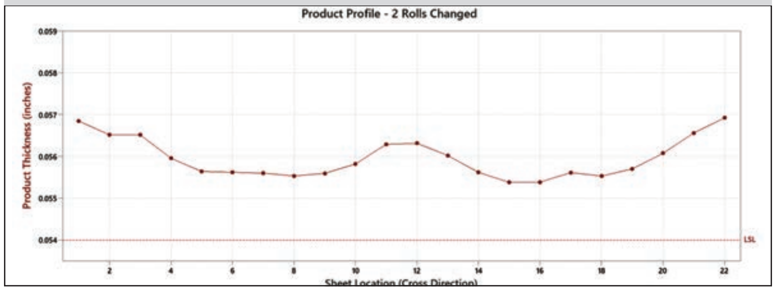


Fig. 3: Product profile – 4 rolls changed.

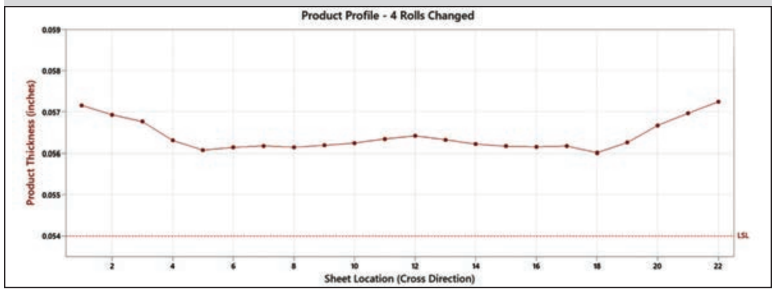


Fig. 4: Product profile and roll shape deviation – before roll changes.

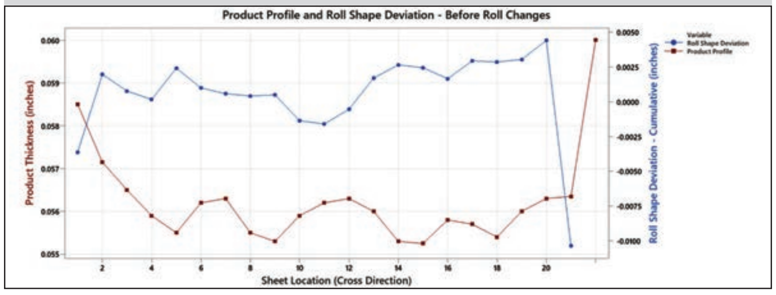
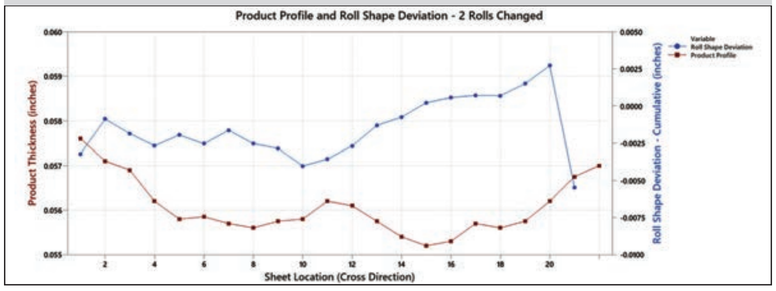


Fig. 5: Product profile and roll shape deviation – 2 rolls changed.



The authors

The Applications Engineering team at Precision Roll Grinders (PRG) consists of a diverse group of professionals with expertise in business, physics, statistics and engineering. This multidisciplinary team works with industry partners to develop and implement solutions for improving manufacturing processes in quality and value enhancement.

Schmidt

Greg Schmidt joined PRG in 2018 and has since then been connecting the sales, marketing and engineering departments. By leveraging his bachelor's in engineering and his Six Sigma Black Belt training, he quantifies the value of PRG's services in a variety of fields, including paper, battery, rubber and seed oil.

Caroline Roberts is an applications engineer with PRG. She holds a master's in physics, a doctorate in astronomy, and a bachelor's in physics. In her work with PRG, she studies the impact of precision roll grinds on customers' manufacturing processes, aiming to aid the rubber, plastic, paper, battery, food, metal and nonwovens industries.

Frances Schmidt, who has experience in physics, mathematics and research, joined PRG in 2022. Her work involves conducting impartial Six Sigma research for companies to analyze the impact of precision calender rolls in their manufacturing processes.

Drew Brady brings expertise to PRG with quantitative methods, statistics and mathematical modeling. His work includes Six Sigma studies that help clients improve product quality, consistency and profitability. He holds a bachelor's in economics, and minors in business and statistical analysis.

in the 10,000-foot simulated total length was calculated and all results were totaled. The resulting estimated rubber usage per 10,000 feet of simulated production from before and after all calender roll grinds is shown in **Table 3**. It is noteworthy that once all four precision-ground calender rolls were installed, the total volume of material used initially went up, due to the absence of thin spots in the sheet. However this increase can be fully eliminated by taking advantage of the opportunity for process adjustment as discussed below.

Results and discussion

Material savings opportunity from the new variation control can be calculated by determining the value for profile gauge reduction C_r, the amount by which the facility could safely reduce the thickness profile of the EPDM sheet by adjusting the process. The facility's LSL for the product is 0.0540 inches but only a conservative LSL of 0.0550 inch was subtracted from the lowest point seen on the product profile after all four calender rolls were ground and changed. As seen in **Fig. 7**, the material savings opportunity 0.0010 inch is shown as a green box. The gray box represents a protective cushion on the facility's true LSL.

The equation for potential EPDM material savings in the facility's process per 10,000 feet of simulated production is:

$$M-(M_{su} — (L_s * W_s * C_r)),$$

where M is 472.8 ft^3 or the total simulated rubber usage before any roll changes, M_{su} is 476.9 ft^3 or the total simulated rubber usage after all four rolls are changed, L_s is the simulated total length of 10,000 feet, W_s is the simulated width of 121.7 inches or 10.14 feet, and C_r is the profile gauge reduction of 0.0010 inch or 0.000083 feet.

From this equation, the daily EPDM material savings per 10,000 feet of production is 4.3 ft^3. At the facility's production rate of 146,880 feet per day, this results in daily savings of 63 ft^3 per day. Using conservative values based on market research, at an EPDM material density of 66 lbs/ft^3 and a price of $1.00 USD/lb, this results in over $4,000 per day in potential savings.

Summary and future work

In this study, the four precision-ground calender rolls installed at a rubber facility led to a product cross direction variation reduction of 29 percent. We established that this improvement in product uniformity allowed for reducing the EPDM thickness by 0.0010 inch, which would lead to significant material savings without increasing the risk to product quality. We quantified a conservative value for this improved product control at more than $4,000 per day.

Even after the achieved reduction in variation of the sheet thickness, we want to look further into the potential application of calender roll crown adjustments. The goal is to further mitigate the variation seen in the final product profile by adjusting the shape and/or magnitude of the calender roll crown. As additional future work, analysis of the long-term product quality data and specific payback is desired to determine the optimal time to grind the four calender rolls going forward. When the details of the roll lifecycle are established, it would allow for further scrap reduction and profit maximization.

Additional avenues for reducing waste include recent advancements in the ability to recycle and reuse EPDM and other rubber materials. In these processes, the vulcanization or curing of rubber is first reversed through various means to revert the elastomer to raw material form, and then the recycled material is combined with rubber than has never been vulcanized. This product with a recycled component is then used in the typical manufacturing applications. Depending on the recycling technique, inclusion of recycled material has been shown to be possible at weight percentages of 20 percent (Mohaved et al., 2015; Gobetti et al., 2024), 40 percent (Sabzekar et al., 2016), and 67 percent (de Sousa et al., 2019) without significant compromise of EPDM performance in metrics such as hardness and compression set. When material waste is reduced through reuse, we aim to test the performance of precision-ground rolls on this recycled rubber to ensure product variation improvement and material savings hold regardless of present recycled component.

In forthcoming studies, we also hope to investigate the impact of tight-tolerance grinds on other EPDM product parameters. Future work would include studying the effect on average tensile strength, hardness, elongation, compression set and adherability, as well as the variation of these values in the sheet cross direction and machine direction. When calender rolls at the facility are replaced with ones that are precision-ground, we aim to quantify any improvements in these metrics and evaluate them in terms of material savings.

Fig. 6: Product profile and roll shape deviation – 4 rolls changed.

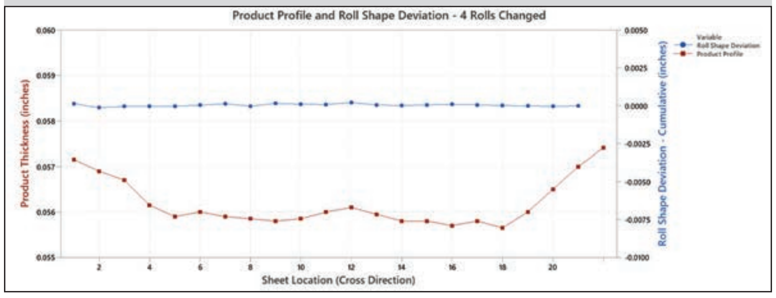


Fig. 7: Material savings opportunity.

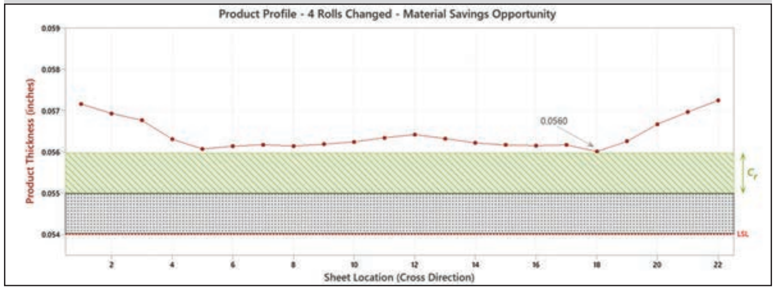


Table 1: Cross direction standard deviation (cumulative roll shape vs. product thickness).

Cross Direction Standard Deviation			
Time Period	**Cumulative Roll Shape Deviation (inches)**	**Mean Product Thickness (inches)**	**Regression Model R-Sq. (%)**
Before Roll Changes	.0031	0.0083	51.84
2 Rolls Changed	.0020	0.0073	24.70
4 Rolls Changed	.0001	0.0059	5.00

Table 2: Simulation parameters.

Simulation Parameters		
Metric	**Parameter**	**Explanation**
Simulated total length	10,000’	Arbitrary
Simulated section length	10’	Arbitrary
Simulated width	121.7”	Average sheet width

Table 3: Total simulated rubber usage.

Total Simulated Rubber Usage	
Time Period	**Rubber Usage (ft^3)**
Before Roll Changes	472.8
4 Rolls Changed	476.9

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