Reducing manufacturing defect through statistical investigation in an integrated aluminium industry

Nandini Das

Abstract Modern philosophy of quality management enhances thrust on customer satisfaction. Achieving continuous improvement in quality is a way to reach the ultimate goal of customer satisfaction. Statistical process control technique is a well-known analytical technique, which is used to solve quality problems in industry. In this paper we present how this technique was used to solve a quality problem through planned data collection and the use of statistical tool. This study was conducted in an integrated aluminium industry in India who was facing poor customer acceptance of one of their high valued product webstock, which was used to produce toothpaste tubes. Pareto analysis showed that a dragging problem, which resulted in a short length of the toothpaste tube, was the most frequent problem. High and inconsistent coefficient of friction (cof) was identified as the root cause of this dragging problem through planned data collection. A detailed and in depth study was initiated to achieve low and consistent cof. Optimum conditions of the process parameters were obtained using design of experiments viz Taguchi's orthogonal array. The recommendations were validated by confirmatory trials. The desired range of output cof was achieved. The recommendations were implemented as a standard operating practice. As a result of implementation the occurrences of the dragging problem was substantially reduced.

Keywords ANOVA · Coefficient of friction · DOE · Orthogonal array · Test of hypothesis

1 Introduction

Customer satisfaction is the key of success in business and industry. The modern philosophy of quality management suggests introducing continuous improvement in product quality to achieve customer satisfaction. The present study was carried out with the aim of achieving customer satisfaction in an integrated aluminium industry in India. The concerned management was facing a problem of poor customer acceptance of one of their premier product, webstock, which they developed recently with a view to tap its mighty export potential. Webstock, which is essentially a laminated aluminum foil produced by a special extruding technology, serves as the raw material for toothpaste tube making in a highly automated plant of a U.S. based client company.

Since Webstock was one of few high value added product of the company and the referred client was the only customer for them it was decided to address the problem of poor customer acceptance of webstock.

2 Background of the problem

Data compiled on customer complaints were analyzed cause-wise and Pareto analysis is shown in the following figure. On an average 40% of the webstock supply was

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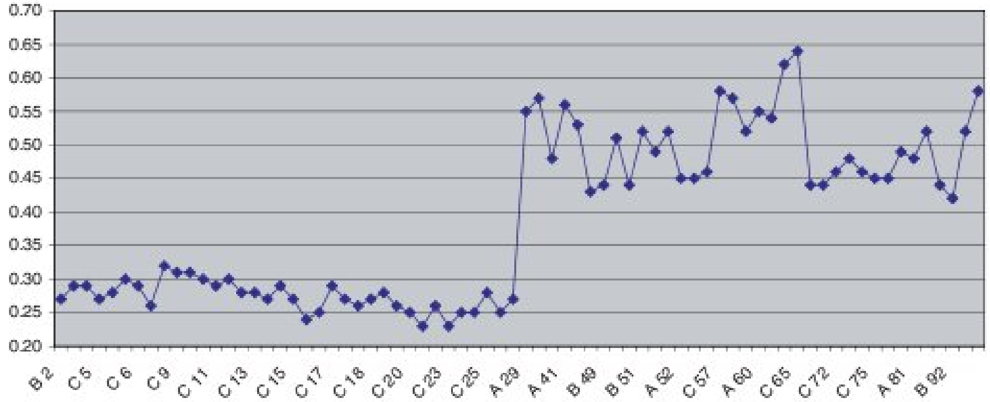
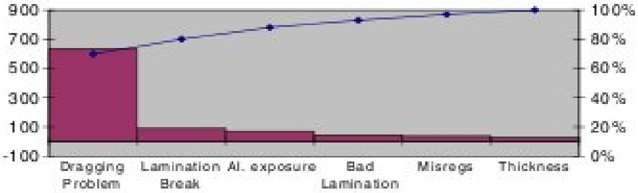
Fig. 1 Line diagram of C.O.F at lamination stage with respect to thread no. (sample No.1)



found as defective material in last three months. Pareto chart is given in chart 1.

Chart 1 Pareto chart of rejection of webstock



From Pareto analysis it was found that the most frequent problem in webstock was dragging problem.

The dragging problem occurred in the customer end while processing the material. While making toothpaste tubes the webstock is fed to slitter with a fixed horizontal speed and the slitter moved vertically. Both movements were controlled separately. A mandrel is used to get tube form.

Because of the dragging effect, the feed of webstock in toothpaste tube making machines slowed down where as slitting movement time remained the same. This resulted in short length of toothpaste tubes causing rejection. Hence the study was initiated to reduce the incidence of the dragging problem.

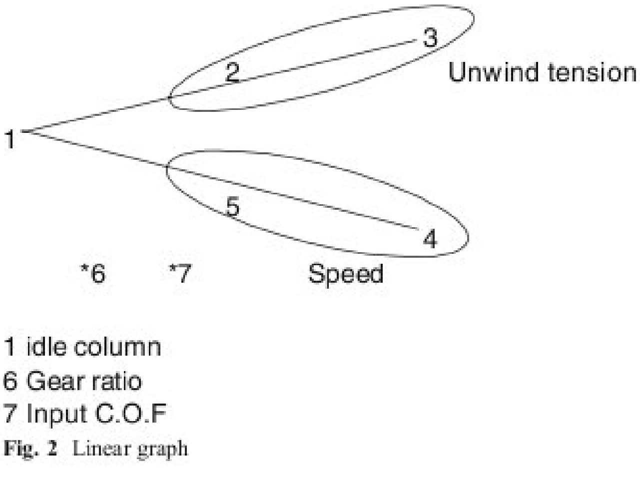


Fig. 2 Linear graph

3 Objective of the study

The objective of the study was to identify the root causes of the dragging problem and to identify appropriate remedial action with a view to get rid of the problem.

4 Root cause identification

A brain storming session was held with technical personnel of the concerned industry and the client company to identify the root causes of dragging problem. The technical personnel from client company, related the dragging problem experienced in webstock supplied by concerned industry to

(i) wide variation in coefficient of friction (C.O.F) of webstock surface.
(ii) Wide deviation from the target C.O.F in the higher side.

To validate it observations were taken on different characteristics of webstock from the concerned industry and their competitor's product. According to the client the competitor's product was free from dragging effect. 300 observations on competitor's webstock were collected on co-efficient of friction. Table 1 gives the comparison of summary statistics of the concerned industry and their competitor's product.

Test of hyphothesis:-

$$H_{01}:\sigma_1^2=\sigma_2^2 \quad H_{11}:\sigma_1^2>\sigma_2^2$$
$$H_{02}:\mu_1=\mu_2 \quad H_{12}:\mu_1>\mu_2$$

Using $\alpha=0.05$, we find $F_{0.05,\,299,59}=1.426$. Here, $F_{cal}=10.462>1.426$, hence we have enough evidence

Table 1 Comparison of concerned industry & their competitor's product w.r.t C.O.F

	Concerned industy'S	Competitor'S
n	300	60
Average	0.69	0.32
Std. dev	0.04	0.013

to reject H_{01}. That indicates that variation of C.O.F for concerned industry's product is higher than that of their competitor's product.

Using $\alpha=0.05$, we find $t_{0.05,\ 358}=1.6498$. Since $t_{cal}=122.597>1.6498$, we can reject H_{02} and we conclude that there is strong statistical evidence to indicate that the average and variation of C.O.F of the concerned industry's product is greater than that of the competitor's product.

The assumption of normality was validated using the normal probability plot given in Figs. 3 and 4.

The above analysis shows that co-efficient of friction of competitor's product is better than that of concerned industry's product with respect to average and variation. The average and variation of C.O.F of competitor's product is significantly less than that of the concerned industry. The other parameters of webstock of the concerned industry, i.e., bond strength, GSM, thickness were well within specification.

Hence it was concluded that the high and inconsistent C.O.F concerned industry's product was responsible for the dragging problem. Hence the objective of the study was boiled down to achieve low and consistent C.O.F for webstock.

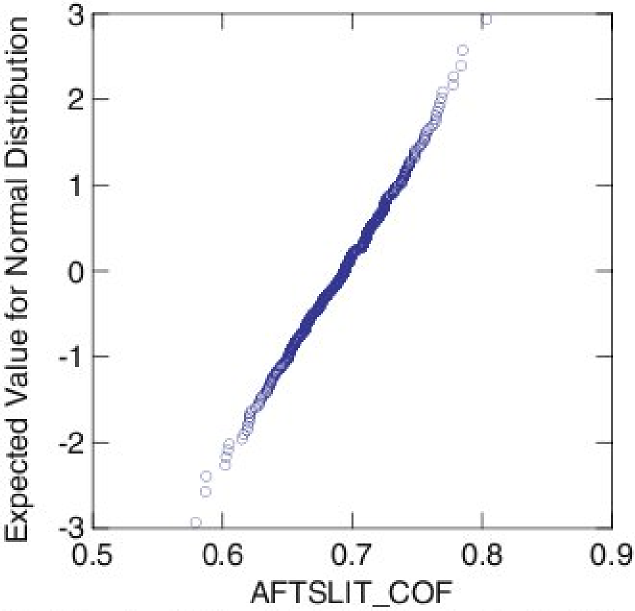


Fig. 3 Normal probability plot of cof of the webstock after slitting (final) produced by concerned industry

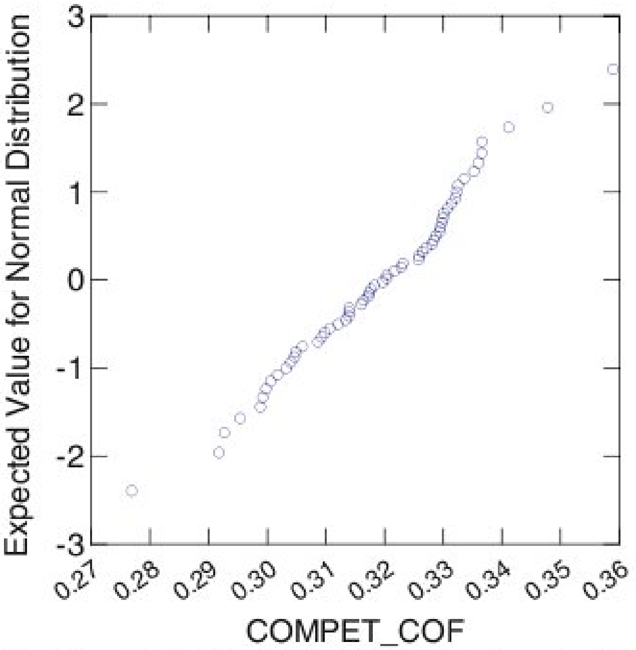
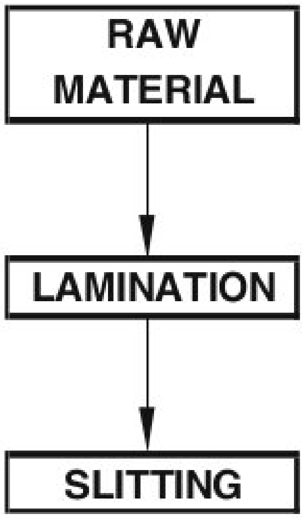


Fig. 4 Normal probability plot of cof of the webstock produced by competitor

5 Process

The process flow chart of webstock is given in chart 2.

Chart 2 Process flow chart



6 Approach

It was decided that the study would be initiated from raw material to slitting stage to identify the problematic area so as to evolve the remedial action to achieve low and c C.O.F

The following steps were followed to get a conclusive result for the present study.

- Raw material (poly) C.O.F analysis
- Study on process variability w.r.t. C.O.F at lamination and slitting stage of webstock
- Detailed study at lamination stage
- Detailed study at slitting stage
- Conclusion
- Recommendation
- Implementation

7 Detailed study

7.1 Data collection & analysis on raw material (poly) cof

Concerned technicians felt that high and inconsistent C.O.F of raw material (poly) may be responsible for high and inconsistent C.O.F at final product.

Eighteen samples were collected along the length from one roll of raw material. For each sample three observations were taken on three different positions (left, middle, and right), and 54 observations were recorded.

Specification for raw material for C.O.F was 0.3±0.1.

$$\begin{aligned} \text{The overall average of C.O.F of poly } x &= 0.299667 \\ \text{S.D.S} &= 0.010095 \\ \#\text{obs n} &= 54 \\ \%\text{Nonconformance} &= 0 \end{aligned}$$

Hence it was concluded that raw material C.O.F were not responsible for the high and inconsistent C.O.F at final output and all values were within specification.

7.2 Process variability analysis at lamination and slitting

Process variability analysis was carried out both at the lamination stage and slitting stage to compare the slitting performance of slitting and lamination stage w.r.t average and variation of C.O.F.

Data were collected on C.O.F after lamination and slitting. The Table 2 gives the comparative statistics of C.O.F after the lamination and slitting stage.

The above statistics were compared with target (0.45) and tolerance (±0.05).

Test of hypothesis: -

1. After lamination:

$$\begin{array}{lll} H_{01}: \sigma_1^2 = \sigma_0^2 \quad H_{11}: \sigma_1^2 < \sigma_0^2 & ; & \text{Where } \sigma_0 = 0.016 \\ H_{02}: \mu_1 = \mu_0 \quad H_{11}: \mu_1 > \mu_0 & ; & \text{Where } \mu_0 = 0.45 \end{array}$$

.

Using α=0.05, we find $\chi^2_{0.95,99} = 77.046$. Here, $\chi_{cal}2 = 57.797 < 77.046$, hence we have enough evidence to reject H_{01}. That indicates that variation of C.O.F after lamination was less than 0.016.

Using α=0.05, we find $t_{0.05,\ 99}=1.66$. Since $t_{cal} = 49.243 > 1.66$, we can reject H_{02} and we conclude that there was strong statistical evidence to indicate that after lamination C.O.F was greater than the target value 0.45.

The assumption of normality was validated using the normal probability plot given in Fig. 5.

2. After slitting:

$$\begin{array}{lll} H_{01}: \sigma_1^2 = \sigma_0^2 \quad H_{02}: \sigma_1^2 > \sigma_0^2 & ; & \text{Where } \sigma_0 = 0.016 \\ H_{02}: \mu_1 = \mu_0 \quad H_{11}: \mu_1 > \mu_0 & ; & \text{Where } \mu_0 = 0.45 \end{array}$$

.

Using α=0.05, we find $\chi^2_{0.05,299} = 340.328$. Here, $\chi^2_{cal} = 693.58 < 340.328$, hence we have enough evidence to reject H_{01}. That indicates that variation of C.O.F after slitting was significantly higher than 0.016.

Using α=0.05, we find $t_{0.05,\ 299}=1.65$. Since $t_{cal} = 96.725 > 1.65$, we can reject H_{02} and we conclude that there was strong statistical evidence to indicate that after slitting C.O.F was very high compared to the target value 0.45.

I. There was a shift in the average level of C.O.F from lamination to slitting.
II. Process variability of C.O.F of the lamination stage was less than that of tolerance (±0.5) whereas process average was on the higher side (0.45).
III. At slitting stage average C.O.F was far from the target and variance was also very high.

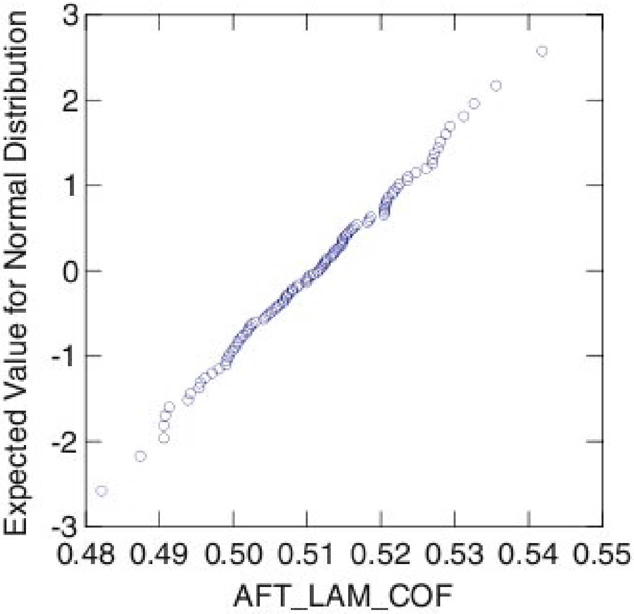


Fig. 5 Normal probability plot of cof of the webstock after lamination stage

Table 2 Comparison of slitting and lamination stage

Statistics	After lamination	After slitting
Average	0.51	0.69
Std. Dev.	0.012	0.04

Hence it was decided to study the lamination stage to identify the root cause for off centering and to study the slitting stage to identify the contributing process parameters for high variability and off centering.

The assumption of normality was validated using the normal probability plot given in Fig. 3 since the same data were used in both Table 1 (first-column) and Table 2 (second column).

7.3 Study at lamination stage to identify the factors affecting off centering of c.o.f values

Discussion with technical personnel revealed that since the webstock was passing through a number of rollers at the lamination stage the effect of roller at the lamination stage on C.O.F must be studied. All the rollers at the lamination stage, which were in contact with natural poly, were identified. Samples were collected before and after each identified roller and the C.O.F value was recorded. The C.O.F values were plotted against the roller number. In Fig. 1 the plots are shown. It was observed that after 29 roller there was a significant shift in average C.O.F value as well as variation of C.O.F value before and after 29 roller.

From the Fig. 1 it was clear that after 29 roller the average and variation of C.O.F was increased. This result was discussed with the concerned technical personnel. Discussion revealed that 29 roller was a drum type roller. Its role was to give support for the web. It was not moving properly. As a result friction was generated which resulted in an increase of C.O.F value. A brainstorming session was arranged to get rid of this problem and all possible alternatives were thought of. A new web path was selected where natural poly was not coming into contact with this 29 roller. Data were collected after each roller in the new web path, which were coming in contact with natural poly. The following table shows the average & s.d of C.O.F value after 29 roller between old web path and new web path.

Table 3 Comparison of performance of old and new web path

Statistics	Old web path	New web path
Average	0.52	0.46
S	0.0029	0.000967

Table 4 Factors and levels of the experiment at slitting stage

Factor	Level–1	Level–2	Level–3
Input C.O.F	LOW (0.38–0.42)	HIGH (0.48–0.52)	——
Gear ratio	7.5:11	11:7.5	——
Unwind tension	10	25	40
Speed	50	100	150

It was observed that in the new web path the average value of C.O.F after 29 roller was 0.46, which was significantly less than that of old web path.

Test of hypothesis: (comparison of average and variation of new and old webpath after 29 roller, Table 3)

$$\mathrm{H}_{01}:\sigma_1^2=\sigma_2^2 \quad \mathrm{H}_{11}:\sigma_1^2>\sigma_2^2$$

$$\mathrm{H}_{02}:\mu_1=\mu_2 \quad \mathrm{H}_{12}:\mu_1>\mu_2$$

Using $\alpha=0.05$, we find $F_{0.05,71,63}=1.504$. Here, $F_{cal}=3.027>1.504$, hence we have enough evidence to say that variance of C.O.F of webstock after roller 29 in old web path was higher than that of in new web path.

Using $\alpha=0.05$, we find $t_{0.05,\ 117}=1.658$. Since $t_{cal}=7.6>1.658$, we can reject H_{01} and we conclude that there was strong statistical evidence to indicate that average C.O.F of webstock after roller-29 in the old web path was greater than that of the new web path.

Since it was shown earlier that the cof after lamination stage follows normal distribution (Fig. 5) the test was not repeated here.

It was concluded from the above analysis that in the new web path the average C.O.F and variation in C.O.F was less than that of the old web path.

Confirmatory trials were run with the new web path and the average C.O.F after lamination was observed as 0.46 and variability was 0.028. With the new web path data on C.O.F were collected after slitting. The average was found to be 0.49 and standard deviation was 0.032. As the average and variability was still high it was thought of to study at slitting stage (i) to validate the effectiveness of the new web path, and (ii) to obtain the optimum combination of process parameters at slitting to achieve low average and variation in C.O.F after slitting.

Table 5 Column assignment

Column	Factor
1	Idle
1,2&3	Unwind tension
1,4&5	Speed
6	Gear ratio
7	Input C.O.F

Table 6 Experimental lay out

Trial no	Idle column	Unwinding tension	Speed	Gear ratio	Input cof
1	1	1	1	1	1
2	1	2	2	1	1
3	2	2	2	1	2
4	2	3	3	1	2
5	1	1	2	2	2
6	1	2	1	2	2
7	2	2	3	2	1
8	2	3	2	2	1

7.4 Study on identifying optimum combination of process parameters at slitting stage to get low and consistent C.O.F

After implementation of corrective action in the lamination stage it was noticed that the average and variability of C. O. F of the final metal was still high. Since after the lamination stage the material was passed through the slitting stage it was decided to initiate a experimental study at the slitting stage.

After discussing with concerned technical personnel the following factors at the slitting stage were identified for further reducing the average and variance of C.O.F (Table 4).

1. Input C.O.F (i.e., C.O.F after lamination stage)
2. Gear ratio (which controls rewind tension)
3. Unwind tension
4. Speed

In statistical design of experiment it is essential to fix the number of levels of the factors before choosing the design. Generally the number of levels do not exceed three because of the following fact. An increase in the number of levels will increase the number of trials and possibility of introducing higher order interaction which are generally difficult to explain in a practical situation. Again there were constraints of practical difficulties of conducting the experiment with a greater number of levels. Hence taking technical matters into consideration and discussing with concerned technical personnel the following factor level combination was selected.

Table 8 Average table for usual ANOVA

Significant factor	Level 1	Level 2
Input C.O.F.	0.44	0.473
Gear ratio	0.468	0.445
Unwind tension	0.445	0.48

The experiment was conducted with first two factors varying at two levels and last two varying at three levels. The following table gives the level of each factor.

L_8 orthogonal array [3] was selected for experimentation. The following table gives assignment of column of L_8 for different factors (Table 5).

Linear graph [3] was given in Fig. 2.

Experimental lay out was given in Table 6.

Analysis of variance or ANOVA [2, 3] of the experimented data was given in Table 7.

From analysis of variance (ANOVA) it can be concluded that the following factors were significantly affecting the average and dispersion of C.O.F after slitting.

- Input C.O.F
- Gear ratio
- Unwind tension (level 1 & level 2)

The optimum combination was obtained from average table. Table 8 gives the average table for significant factor in usual ANOVA.

8 Conclusions

(1) High and inconsistent C.O.F was the root cause for the dragging problem.
(2) C.O.F of raw material (poly) was not responsible for high and inconsistent C.O.F of webstock.
(3) At the lamination stage the average C.O.F was higher than the desired level but the variation well within tolerance.

Table 7 ANOVA table

Parameter		1 or 2	2 or 3	ss	df	mse	F	p
idle		3.700	3.600	0.001	1	0.001	1.866	0.209
unwinding	1–2	1.780	1.920	0.002	1	0.002	7.306	0.027
	2–3	1.813	1.787	0.000	1	0.000	0.266	0.620
speed	1–2	1.883	1.817	0.001	1	0.001	1.651	0.235
	2–3	1.847	1.753	0.001	1	0.001	3.263	0.108
gear ratio		3.743	3.557	0.002	1	0.002	6.499	0.034
input cof		3.517	3.783	0.004	1	0.004	13.286	0.007
Error				0.003	8	0.000		
Total		3.345	7.300	0.014	15	0.001		

(4) Roller 29 was having a significant effect in resulting shift of average of C.O.F after the lamination stage.
(5) The slitting process was not capable of meeting target and tolerance for C.O.F with old web path.
(6) Input C.O.F of slitting process (C.O.F after lamination), gear ratio and unwind tension was a significant factor affecting high average and high variation of C.O.F after slitting.

9 Recommendation

1. The new web path at lamination stage was recommended for standard operating practice.
2. At slitting stage optimum combination obtained from the experiment was recommended.

A. Input C.O.F(C.O.F after lamination) = Low
B. Gear ratio = 11 : 7.5
C. Unwind tension = 10

The expected average C.O.F after slitting=0.417.

10 Confirmatory trial

Confirmatory trials were made with the recommended web path at the lamination stage and recommended levels at the slitting stage. The data on C.O.F along with the other product characteristic viz. bond strength, gsm, thickness were collected. It was observed that bond strength, gsm, thickness were well within the spec and the values of cof were within 0.40–0.45. It was quite clear that after implementing the recommendations low C.O.F has been achieved and the other characteristics did not deteriorate.

11 Implementation

The results were discussed with concerned management. The recommendations were implemented as standard operating practice and as a result of implementation the amount of dragging problem was substantially reduced.

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