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Outliers Effect in Measurement Data for T-peel Adhesion Test using Robust Parameter Design

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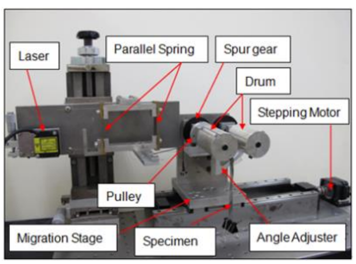
Graphical abstract



Abstract

As many researches focused on application of robust design engineering in practical case study, very less concerned on the criticality to data measurement system in parameter design. This paper will emphasize on the importance to be critical to data obtained during experiment. The existence of outliers is often ignored and the impact overlooked, thus endanger the results by producing false alarm and giving completely wrong parameter setting. The optimum condition from the data that contains outliers is compared with the corrected data measurement. The finding presents the indication procedure on how to confirm whether the data is reliable or not for evaluation. The data is unreliable when two main indicators are detected. Firstly, the measurement data plot detects outlier through linear regression analysis as it does not belong on the linear line. Secondly, poor reproducibility presented by estimation and confirmation of signal-to-noise ratio. This failure affects the experimental design and lead to wrong optimum condition. T-peel adhesion test using orthogonal array L9 is done as a case study to elucidate the detection of outlier and outlier effect on optimum condition.

Keywords: Robust parameter design method; Al-CPP flexible film; outliers; linear regression; dynamic signal-to-noise ratio; T-peel test; peel strength

Abstrak

Pelbagai kajian telah difokuskan pada aplikasi kejuruteraan reka bentuk mantap (*robust*) sebagai kajian kes. Amat sedikit kajian dilakukan ke atas kritikaliti sistem pengukuran data menggunakan reka bentuk parameter. Kajian ini menekankan tentang kepentingan kritikaliti data yang diperolehi dalam suatu eksperimen. Kewujudan titik terpencil sering kali tidak dihiraukan dan dilepas pandang. Ini menyebabkan keputusan tidak jitu lantas mewujudkan kesalahfahaman dalam penaakulan data. Ini seterusnya menjurus kepada kesilapan kondisi optimum yang diperolehi daripada reka bentuk parameter. Kondisi optimum dari data yang mengandungi titik terpencil dibandingkan dengan keputusan data yang tidak mengandungi titik terpencil. Keputusan kajian ini mendedahkan prosedur penilaian kebolehsandaran data. Sesuatu data yang mengandungi kebolehsandaran yang sedikit mempunyai dua jenis penunjuk. Pertama, data yang dioperolehi boleh mengesan titik terpencil dengan kaedah analisis regresi di mana keserakan data adalah besar. Kedua, kebolehulangan yang rendah diperolehi daripada penganggaran dan kepastian *signal-to-noise ratio*. Kegagalan ini memberi kesan kepada eksperimen dan mengundang kondisi optimum yang salah. Ujian perekat *T-peel* menggunakan orthogonal array L9 dilakukan sebagai kajian kes untuk menjelaskan pengesanan titik terpencil dan kesan terhadap kondisi optimum.

Kata kunci: Kaedah reka bentuk parameter mantap; Al-CPP *flexible film*; *outliers; linear regression; dynamic signal-to-noise ratio; T-peel test; peel strength*

1.0 INTRODUCTION

Robust design engineering is an engineering optimization strategy ideally used for the development of new technologies in product and process design [1,2]. One of its component focused in this paper is parameter design which defined as a systematic way to make a design robust against noise factors which takes place in improvement stage of the product development process

[3]. However, the methodology of conducting robust design usually started with data analysis of sum and mean, deviation, variation and variance [4]. None emphasizes on the measurement data before the data can proceed to be analyzed. Data which being affected by extraneous sources of variation other than variation studied in outer array could lead to wrong decision. Investigation has to be made whenever anomalies are found, and outlier analysis is one kind of investigation analysis. In this paper, the criticality to measurement data is discussed on a case study performed in T-peel adhesion test to find an optimum condition of a peel strength measurement system. There are many methods to evaluate peel strength of laminated packaging film such as 90^{o} peel, 180^{o} peel, T-peel test and climbing drum peel test [5]. The packaging film is flexible material and consists of several layers of flexible films. Therefore, T-peel test is the most suitable peel test to measure the peel strength. The peel strength of multilayer film is an important property as practical use for the packaging product. In this paper, T-peel test has been used to measure peel strength on flexible packaging film using new T-peel test apparatus [6]. Thus, it is crucial to establish an optimum testing condition using robust parameter design L9 which has minimum variation in peel strength. For reducing variation, noise factor is taken into consideration. In order to observe the effect of outliers on optimum condition, two L9 are constructed; one with outlier data (L9A) and another one with no outliers (L9B). Experiments were then carried out to detect outlier and its effect on signal-to-noise ratio (SNR). The importance to be critical to data is presented in outlier detection procedure. This paper is organized in the following manner. Firstly, the case methodology of T-peel adhesion test optimization is described as a case study for its measurement process. Next, the measurement data is evaluated for outlier detection through regression plot and reproducibility of experiment. Finally, the paper concludes with a summary of this study.

■2.0 EXPERIMENTAL

2.1 Test Specimen

The specimen used in this experiment is a four-layer packaging film. Full lamination consists of polyethylene terephthalate (PET), polyamide, aluminum foil and cast polypropylene (CPP) is shown in Figure 1:

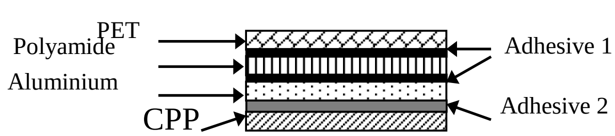


Figure 1 Test specimen

Peel strength is determined in Newton (*N*) measured by the strength required to peel away between the interlayer of cast CPP and aluminium. Peel angle is read from aluminum side of packaging film [6]. Standardized testing method for T-peel test by ASTM D1876 and Japanese Industrial Standard (JIS K 6854-3) are used to measure the peel strength of the flexible composite materials. However, this method is fit for rigid materials and not suitable on flexible film. Large variation occurred due to specimen failure to sustain the peel angle [7]. New testing apparatus had been established to overcome this problem and suit the flexible film peel testing.

2.2 New Test Apparatus

As shown in Figure 2, angle adjuster is used to changed the peel angle according to orthogonal array setting. Specimen is attached at the bottom of the drum, and a weight (paper clip) is fixed on the free-end of the film to keep the specimen in T-shape. When the specimen started to peel, parallel spring is pulled by pulley wire attached on the rotating drum along peeling process. The spring displacement is detected by a laser displacement sensor.

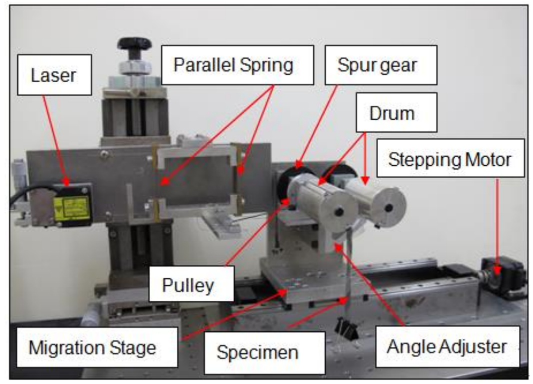


Figure 2 New apparatus for T-Peel test

2.3 Ideal Function and P-Diagram

A dynamic ideal function is used, based on wide range of specimen width. The response, Y; is peel strength, the output from the measurement process with as small unwanted variation as possible. M is the input of signal factor from various range of specimen width for peel strength linearity. Beta,β, is the measurement sensitivity to different inputs, thus the slope must be steep. Therefore, the dynamic ideal function is zero-point proportional Equation [4], Y=βM. P-diagram is described in Figure 3:

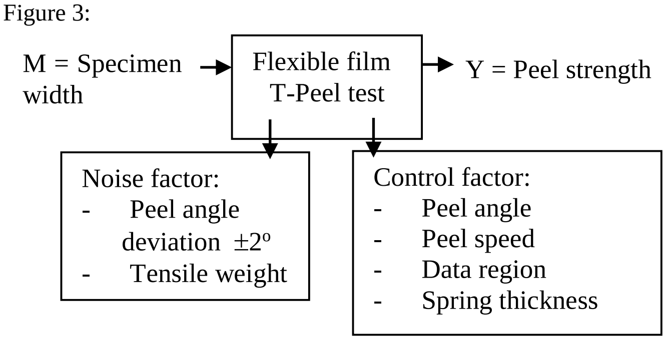


Figure 3 P-diagram of T-peel test

2.4 Control Factor

The control factors are set in inner array chosen based on testing and design condition. Peel angle, peel speed, peeling curve data region, and spring thickness are controllable factors considered based on testing condition and apparatus design.

2.5 Orthogonal Array Selection

Orthogonal array is a balanced set of experimentation runs to explore the design space with small number of experiments [4]. 54 experiments in one L9 is implied for this study (9 x 3 signal level x 2 noise level). Table 1 summarized the factors used in L9. Two L9 are constructed, one with outliers data and another L9 is repeated without outliers

Table 1 Factors and their levels in L9

Control Factor	*Unit*	*Level 1*	*Level 2*	*Level 3*
A: Peel angle	o	60	90	120
B: Peel speed	mm/s	6	9	12
C: Data region	%	30	50	70
D: Spring thickness	mm	0.3	0.4	0.5
Signal Factor				
M: Specimen width	mm	5	10	15
Noise Factor		*N1*	*N2*	
Tensile weight	g	8	4	
Peel angle deviation	o	+2	-2	

2.6 Signal Factor

In the ideal function, the energy transformation occurs for three different specimen width that are 5 mm, 10 mm and 15 mm. These values are chosen based on material specification to evaluate the peel strength at this range of specimen. Signal factor is a controllable variable to actualize the intention to achieve robust condition regardless of various width condition. A dynamic signal-to-noise ratio (SNR) has been used in this study, where the specimen width as the signal factor with 3 levels that are 5 mm, 10 mm and 15 mm is used to measure the peel strength linearity. Hence, signal-to-noise ratio (SNR), η, for dynamic response is used in this study to measure various range of input to ensure robustness.

$$\eta = 10 \log [(1/(r_o \cdot r)) (S_\beta - V_e) / V_N] \quad (1)$$

2.7 Noise Factor

Noise factor is a factor that cause variation in measurement system. For noise factor, peel angle deviation of ± 2 degrees is chosen as shown in Figure 4 based on previous experience. It is observed from preliminary study that $\pm 2^o$ is a rough estimation for peeling angle distribution. By using that result, it is decided $\pm 2^o$ as the level for the uncontrollable factor. Peel angle is adjusted in three levels that are 60^o, 90^o and 120^o. The angle would vary during exchanging the peel angle and along peeling process. Therefore, noise in peel angle is defined as deterioration in $\pm 2^o$ for each level. Tensile weight of 4g and 8g is also considered as noise factor because a weight is loaded at the end of specimen to sustain the T-shape.

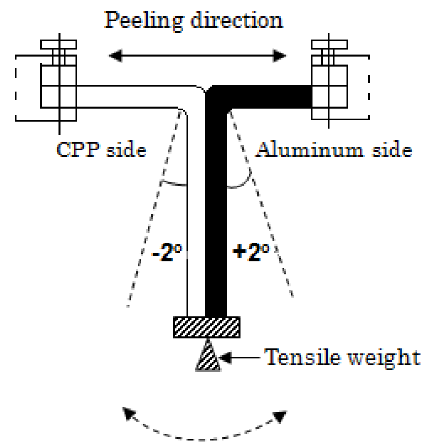


Figure 4 Deviation in peel angle during T-peel

Noise 1 is the higher level ($N1 = +2^o$ and 8g) and Noise 2 is the lower level for ($N2 = -2^o$ and 4g). N1 and N2 are arranged in outer array to study the variation effect when combine with control factors and signal factors. Table 2 summarized the noise factor:

Table 2 Noise factor for L9

N1	N2
62°, 8g	58°, 4g
92°, 8g	88°, 4g
122°, 8g	118°, 4g

■3.0 RESULTS AND DISCUSSION

Peel strength result is taken for SNR calculation. First measurement result is labelled as L9A and shown in Table 3. The data, Y*ij*, is assumed independent and in normal distribution.

Table 3 L9A result

Run	Specimen width (mm) 5		10		15		SNR η(dB)
1	9.07	8.44	16.21	16.88	25.25	26.13	10.03
2	7.92	7.85	14.95	15.19	22.22	21.75	11.20
3	9.61	9.45	19.01	20.93	27.72	30.47	4.87
4	8.04	8.44	19.57	20.32	27.62	30.07	3.55
5	8.52	8.21	16.84	17.21	26.05	25.68	16.27
6	7.57	8.17	15.77	15.55	21.72	22.44	7.69
7	6.39	6.49	13.52	13.71	20.14	20.58	14.18
8	12.88	8.21	20.86	20.52	29.60	30.22	2.20
9	7.69	7.08	17.30	16.50	24.87	23.75	6.37

SNR, $\eta = 10 \log (1/r) [(S_\beta - V_e) / V_N] \quad (1)$

$$S_\beta = \frac{((9.07+8.44)5+(16.21+16.88)10+(25.25+26.13)15)^2}{2(5^2+10^2+15^2)}$$

$$V_e = S_e/f_e = (S_T - S_\beta - S_{N x \beta}) / 4 \quad (2)$$

$$S_T = 9.07^2+8.44^2+16.21^2+16.88^2+25.25^2+26.13^2$$

$$S_{N x \beta} = ((9.07)5+(16.21)10+(25.25)15)^2+((8.44)5+(16.88)10+(26.13)15)^2) / (5^2+10^2+15^2) - S_\beta$$

$$V_N = S_e' / f_e' = (S_T - S_\beta) / 5 = 0.29 \quad (3)$$

$$\eta = 10 \log_{10}(1/2(5^2+10^2+15^2))[(S_\beta - V_e) / V_N] = 10.03\text{dB}$$

Once the result is obtained, it is important to critically analyze the data before proceeding further analysis. Otherwise, the analysis of improper data will endanger the experiment and lead to improper conclusion. Linear regression plot is one alternative to investigate the existance of outliers. Measurement data for L9A is shown in Figure 5.

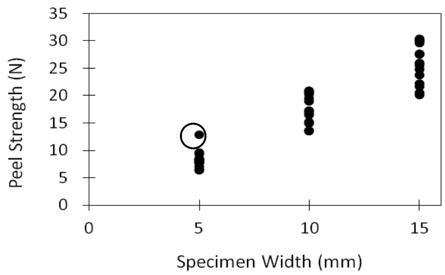


Figure 5 L9A measurement data

In 5 mm, one outlier is detected as it does not belong to its population group. Peel strength of that one point is abnormally different, that is 12.88 N. The investigation is continued by plotting the regression plot for 5 mm as in Figure 6 to investigate the problem. N1 and N2 are assumed as two variables and the correlation coefficient, r, is used to measure the linear relationship between two variables. The squared coefficient of correlation, R^2, gives the proportion of common variance between two variables, also called coefficient of determination [8]. The closer the value of R^2 is to 1, the stronger the linear association between the variables. One extremely deviant observation, so-called outlier, can dramatically influence the value of R^2 [8]. In Figure 6, R^2 without outlier is 0.766, but when the outlier is added to the set, the correlation is equal to -1.935. R^2 can never be negative as it is the square of r. The value of R^2 is bounded by $0 < R^2 < 1$. The existance of outlier presents a suspicious observation and the result need to be repeated to confirm the cause or else it might lead to wrong conclusion. In L9A, the outlier data is 12.88 N in run 8 for specimen 5 mm under N1. Outlier is not observed in specimen 10 mm and 15 mm as R^2 for specimen 10 mm and 15 mm is 0.910 and 0.895 respectively. Then, mean SNR so-called process average is calculated to find the effect of each control factor. The process average is used to calculate the optimum condition based on SNR factorial effect plot.

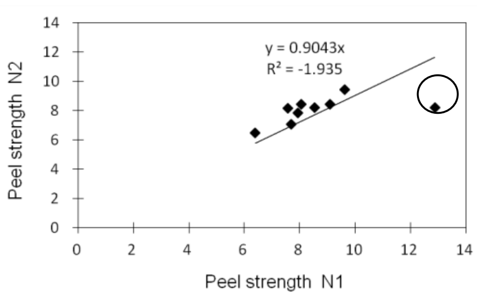


Figure 6 Specimen 5 mm measurement result

Optimum condition for L9A derived from SNR formula in (1) is A2 B2 C3 and D2. The detection procedure is proceeded by checking the experiment reproducibility through comparison of SNR estimation and confirmation dB gain. Estimation of SNR for optimum condition is calculated by:

$= A2+B2+C3+D2 – (DOF\ n\text{-}1)(\Sigma\eta / n)$ (4)
= (A2+B2+C3+D2) – (4 factor–1)(average SNR in L9A)
= 41.84dB – 3(8.48dB) = 16.39dB

Estimation of SNR for worst condition is calculated to get the dB gain. The effect of the optimum condition is shown by the dB gain size.

= (A3+B3+C1+D3) – (4 factor–1)(average SNR in L9A)
= 24.07dB – 3(8.48dB) = - 1.38dB

Thus, estimated dB gain is 17.77 dB. Confirmation run is done to ensure the reproducibility of optimum condition. However, the confirmation of dB gain is 9.75 dB, which is 45.1% different from estimation dB gain. The result of the experiment is considered not satisfactory. This indicates the possibility of wrong optimum condition resulting from outlier data. The dB gain difference should not exceed 30% difference from estimated dB gain [9]. From the anomaly of R^2 and dB gain difference, a second L9 which is called L9B in Table 4 is employed as to repeat the experiment and to confirm the outlier reproducibility. All 9 runs are conducted again to reduce extraneuos sources of variation.

Table 4 L9B result (repeated experiment)

Run	Specimen width (mm)						SNR η
	5		10		15		(dB)
1	8.70	8.37	16.62	16.78	24.96	24.09	12.40
2	8.04	8.12	15.28	16.21	23.91	24.52	11.77
3	8.72	8.09	16.59	16.39	24.49	24.30	15.15
4	7.79	8.04	15.68	15.86	23.87	24.38	15.97
5	8.45	8.41	16.49	16.20	24.12	23.99	14.85
6	8.26	8.18	15.51	15.80	24.43	24.32	13.28
7	7.59	7.74	14.77	15.15	22.16	22.20	16.76
8	7.46	7.69	15.03	15.83	22.68	23.58	11.76
9	8.49	8.27	15.87	16.29	23.76	24.09	14.43

Measurement data of L9B is plotted to observe any outlier. R^2 for 5 mm, 10 mm, and 15 mm are 0.729, 0.676, and 0.645 respectively. No outlier is observed. The outlier in L9A is a special cause, due to environment noise or measurement mistake that cause the 12.88N as outlier data. SNR as in (1), SNR process average and effect plot, and estimation SNR as in (4) are calculated for L9A. The optimum condition for L9B is A2 B1 C3 D3 as shown in Figure 7. The estimated dB gain is 7.31dB and confirmation dB gain is 6.53dB. Table 5 summarized only 10.7% difference, thus L9B is considered a success:

Table 5 Producibility examination for L9And L9B

Type	Condition	Estimated	Confirmation
L9A	Optimum	16.39	15.10
A2	Worst	-1.38	5.35
B2	SNR dB gain	17.77	9.75
C3	Gain difference	8.02 dB (45.1% difference)	
D2			
L9B	Optimum	17.49	16.45
A2	Worst	10.18	9.92
B1	SNR dB gain	7.31	6.53
C3	Gain difference	0.78 dB (10.7% difference)	
D3			

Notice that there are some deviations between condition L9A and L9B. SNR for L9B is higher than L9A due to repetition error since L9B is done after realizing the outlier existing, which took some time gap between both experiment. The variation is also due to extraneous factors which inevitably vary during experiment such as temperature and humidity. As the paper focused on the effect of outlier from response data and its influence on optimum condition, the difference in optimum condition level between separated data set is assumed as having no effect in outlier examination.

■4.0 CONCLUSION

The importance of making thorough analysis of assumptions and possible existence of outliers have become obvious from the case study in this paper.

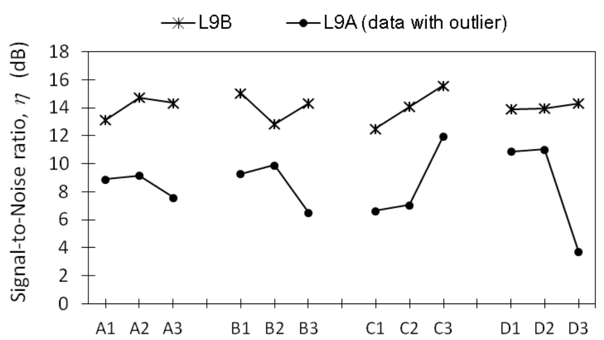


Figure 7 SNR factorial effect plot for L9B and L9A

Eventhough the confirmation test indicated the problem and thus trigger suspicious to data, a thorough investigation of possible anomalies in measurement data should be performed. Thus, it is very important to ensure that the data is reliable enough to draw a conclusion at the end of the experiment by:

a) Outliers examination - by observing the linear relationship in regression plot. R^2 changed dramatically when deviant observation is found.
b) Reproducibility examination – Estimation and confirmation in dB gain difference should not deviates too much or exceeds 30%. The similar the value between estimation and confirmation SNR, thus more reliable the optimum condition is.

Figure 8 gives a summary of the outlier checking methodology to prevent any misleading conclusion from SNR analysis. Planning the experiment carefully is extremely important to ensure a smooth and reliable result. Enable the function, quality characteristic selection, and noise, control and orthogonal array selection is done in Plan stage. When planning is completed, experiment is ready to be implemented thus labeled as Do stage. Before confirming the SNR result, linear regression from the measurement data is plotted to observe any abnormalities and extraneous variation.

Reproducibility in measurement is analyzed through confirmation experiment by comparing the dB gain between estimation and confirmation SNR. If the condition of sample has changed, the experiment is necessary to be repeated because variation is greater for a sample that has changed its condition. However, if the sample has no changed condition (short period of time), it is sufficient to be treated as missing data treatment through linear regression. Replacement of regression point found in linear regression analysis is done instead of doing another new experiment. Finally, the optimum level is accepted as an action for further application of the confirmed optimum condition. Measurement data should be examined immediately once the experiment is performed to prevent costly mistakes.

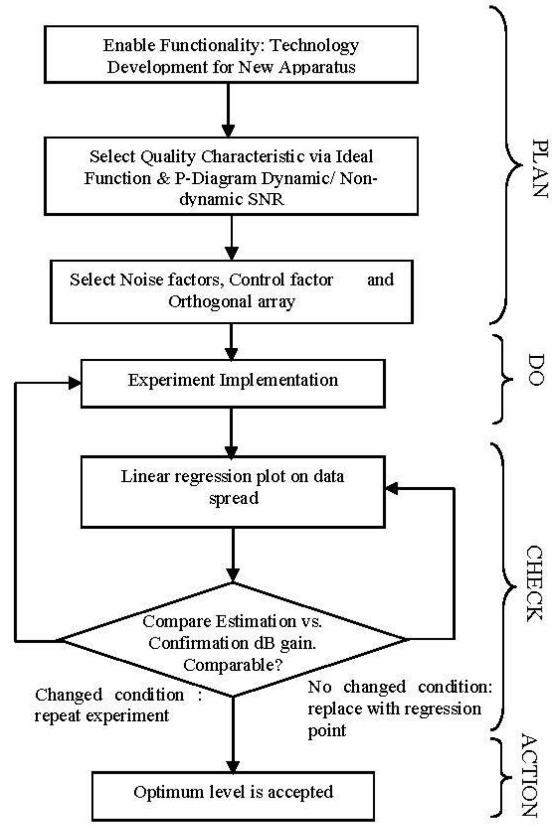


Figure 8 Methodology for robust parameter design

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