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Investigation of Curing Process on Synthetic Leather Substrates

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Abstract: Synthetic leather is a durable material with a similar appearance and durability to real leather at a lower cost, most commonly used in the printing industry for many purposes. Over the past several decades, ultraviolet printing (UV) has shown great potential in synthetic leather printing with good speed and quality. However, some drawbacks were found, including graphical structure can crack or quickly pull down on the synthetic leather surface. UV ink is not fully cured, causing materials to remain sticky or wet to the touch after the printing. Not to mention, UV ink giving an unpleasant odour and cause some health problems due to over-exposure to UV light. Therefore, based on the full factorial design of the experiment's method (DoE), a predictive model using Minitab software was used to characterizing and optimizing the curing parameters for the curing process on PVC synthetic leather substrates. Then, validate the results using existing curing techniques, Delone M2 – 1800. This contribution evaluates the optimum level for input parameters correspond to line width and pattern edge response values. The obtained results from Minitab software show curing temperature at 50°C, 60°C, and 70°C, and curing time at VSD_2, VSD_3, and VSD_4 are significant for curing the PVC synthetic leather substrates.

Keywords: Curing, PVC Synthetic Leather, Substrates, Minitab, Design Of Experiment (Doe), Full Factorial Method

1. Introduction

Synthetic leather or faux leather, meaning fake in French words [1], is a leather-based alternative to real leather. It is a durable material with a similar appearance and sturdiness to real leather at a lower cost [2]. It is widely utilized in the printing industry for many purposes, from clothing such as jackets and skirts to accessories like belts, wallets, handbags, and even shoes. Polyvinyl chloride (PVC) is one of the most employed thermoplastic materials to produce synthetic leather. Due to the presence of hydrogen chloride (-HCl-) in the polymer monomer (–[CH2–CHCl]n–), it increases the interchain interaction through dipole-dipole forces, which make PVC resulting in low thermal stability [3] and increasing flexibility and workability through plasticizers absorption [2]. As a result, its addition will increase PVC performance and can be used in different areas.

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Today we can see that the function of synthetic leather is overtaken and widely enhanced by ultraviolet printing. Ultraviolet printing (UV) has shown great potential in synthetic leather printing where up until now, it offers a range of advantages that more basic printing options cannot provide: more efficient, green-friendly, coating quality, low solvent levels, faster cure time, and delivering high-quality output [4]. It also effectively bonds to non-absorbent surfaces [5] through crosslinking and polymerization, consisting of four components: monomers, oligomers, pigments, and photoinitiators [4]. With the continually evolving, it is no wonder UV printers are the fastest growing digital printing in large format markets. While there is much gain from this approach, this technology is still under development and needs to be evaluated. It is found out that the graphical structure can crack or quickly pulls down on a synthetic leather surface [1], and UV ink is not fully cured, causing the material to remain sticky or wet to touch after the printing. Furthermore, uncured UV ink giving an unpleasant odour [6] and is more like to cause skin damage and health problems [7].

The overarching aims of the study were twofold: (a) the feasibility of existing curing technique to be used for curing process on synthetic leather substrates; (b) to determine the suitable variation, optimum and significant factor levels of curing parameters to cure the ink properly on synthetic leather substrates. Here, Minitab statistical software (Full Factorial Method) was used to characterize and optimize the curing parameters on PVC synthetic leather substrates and validate the results using existing curing techniques, Delone M2 – 1800.

2. Materials and Methods

2.1 Materials

The eco-solvent ink is an import ink purchased from Inkcowell Company, Penang, Malaysia, designed explicitly for inkjet printing with the Delone M2 – 1800 model. It is odourless, low cost, and has intense colour saturation. The supply system is in tank and cartridge (siphon), and there will be four colours used: cyan, yellow, magenta, and black (CYMK). These materials then will be employed on polyvinylchloride (PVC) synthetic leather model G90G (dimension 1.27x50 inches) with its specification such as high tack grey removable glue, 140g kraft paper, high gloss, super smooth, and can be used for different surface as a substrate. The synthetic leather was supplied in one roll by Delone Digital Technology Sdn Bhd. The proposed printed design substrate is shown in Figure 1.

Figure 1: Simple and intricate pattern design on PVC synthetic leather substrates

2.2 Method

Before performing the experiment, appropriate curing parameters are identified and characterized into input parameters: curing temperature and curing time; meanwhile, response parameters are taken as line width and pattern edge of design substrates. Next, a full factorial method was selected using Minitab to analyze all those significant results for each level of curing parameters and applied the optimum value from curing parameters into the printing and curing experiment using Delone M2 – 1800.

A validation through two types of reliability tests: smear testing and adhesion testing, will be conducted to see whether the optimum value of curing temperature and curing time has met the reliability criteria. Once the reliability outcome has been identified, morphological analysis is then implemented using optical microscopy (OM) to evaluate any physical changes on printed substrates' line width and pattern edge. Lastly, a colour assessment using a CYMK colour chart will be applied to see any differences between the colour displayed on the screen monitor and the printed version.

3. Results and Discussion

3.1 Result of Simulation: Selection of Significance of Curing Parameters

Before the actual curing process is being performed, the selection of significance curing parameters should be conducted to find which curing parameters affected the most on the substrates. A simulation should perform via Minitab based on observation on the Pareto Chart of Standardized Effects ($\alpha = 0.05$), Mean effects plot, and Interaction plot has been analyzed to determine which parameters are important in the curing process. Four curing parameters including curing temperature, curing time, ink layer thickness, light source intensity and pH pigment of the ink, were determined in the curing process as listed in Table 1. These parameters help obtain synthetic leather with a proper curing process and attain good ink adhesion ink to the substrate's surface [8]. Meanwhile, as tabulated in Table 2, the response parameters, including line width and pattern edge, were randomly taken from the SolidWorks drawing.

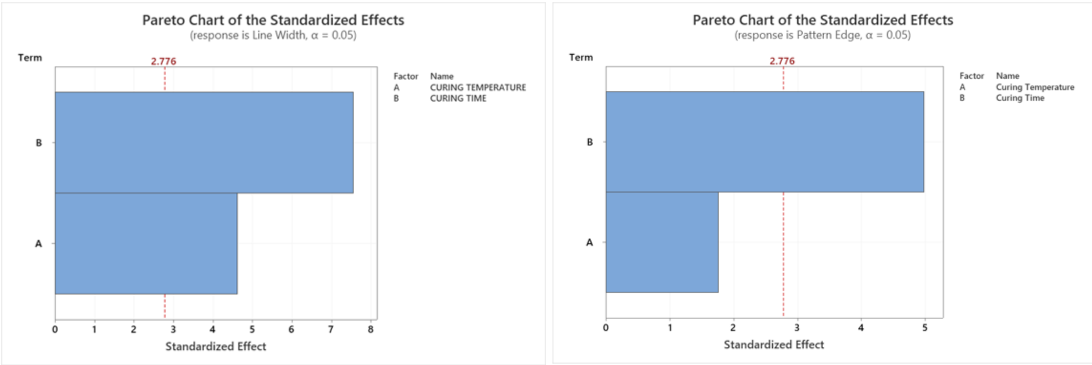
Table 1: Table of input curing parameters and the setting values

Input parameters	Value
Curing temperature (°C)	Range 0 – 100
Curing time (VSD)	Range from VSD 1 – VSD 4
Ink layer thickness (μm)	Range from 20 - 100
Light source intensity (mW/cm^2)	Range from 200 - 600

Table 2: Response parameters and the setting values

Trial no	Line width (mm)	Pattern edge (mm)
1	41	30
2	5	25
3	50	2
4	5	35
5	1	6
6	27	10
7	35	7
8	1	41
9	25	1

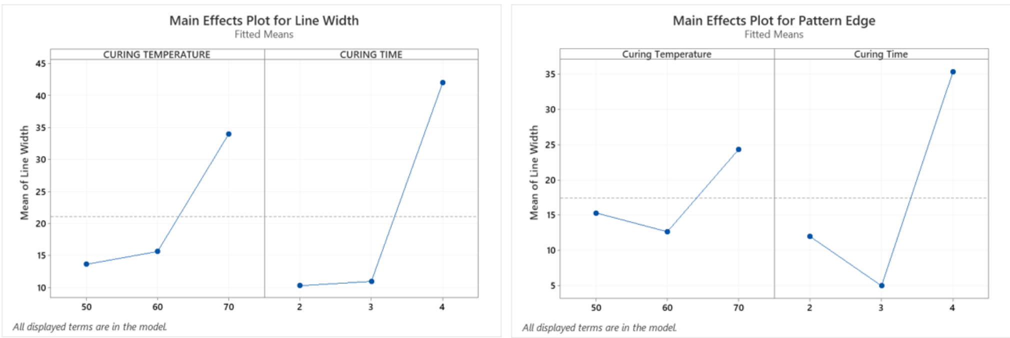
Figure 3 (a) shows the Pareto chart of curing temperature and curing time with line width as a response value. The factors A and B crossing the red dotted line show that these factors are significant at a 97% confidence level. Any effects that extend beyond the reference line are significant [9]. Meanwhile, Figure 3 (b) is statistically significant at 92% confidence level. Only one factor crosses near the red dot line, which factors are important but have a minor effect on the response parameter [10].



(a) (b)

Figure 2: Pareto chart for curing temperature and curing time on (a) line width (b) pattern edge

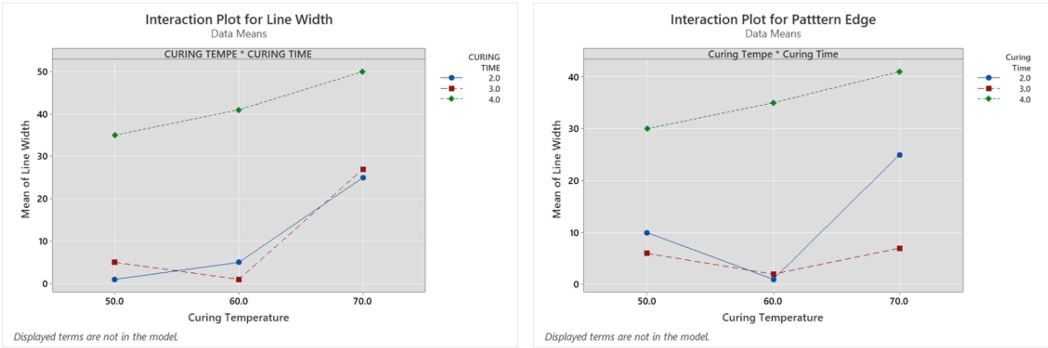
This can also be supported through the Main effects plot. One can observe and validate that curing parameters in the highest value is significant through Figure 4 (a) and 4 (b) graphically shows the same trend at the most convincing parameters. A longer curing time have an adverse effect and provides more energy to strengthen the polymerization of the ink particles on prints substrate [11].



(a) (b)

Figure 3: Main effects plot for curing temperature and curing time on (a) line width (b) pattern edge

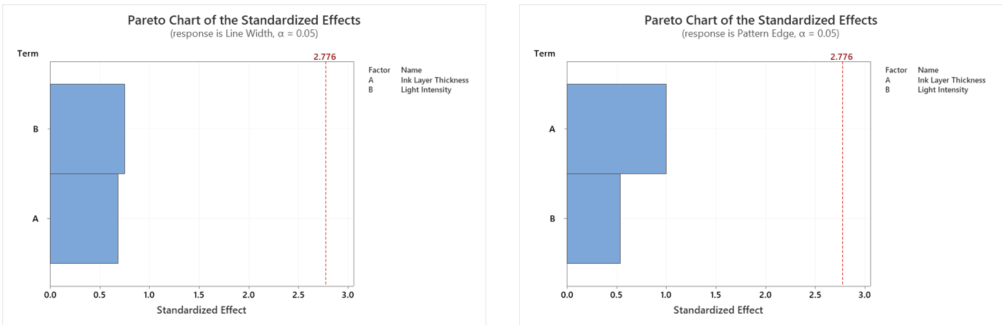
Other than that, when the interaction at a factor level is dependent on the levels of other factors, the interaction exists since it can diminish the main effects of the parameters [10]. The interaction plot from Figure 5 (a) and 5 (b), shows more nonparallel lines, which there is stronger interaction between input and response parameters [12]. However, An ANOVA test should be run to determine the statistical significance of the effects through the p-value from the ANOVA table. All the linear are less than or equivalent to the level of significance as their p-value is < 0.1 [10]



(a) (b)

Figure 4: Interaction plot for curing temperature and curing time on (a) line width (b) pattern edge

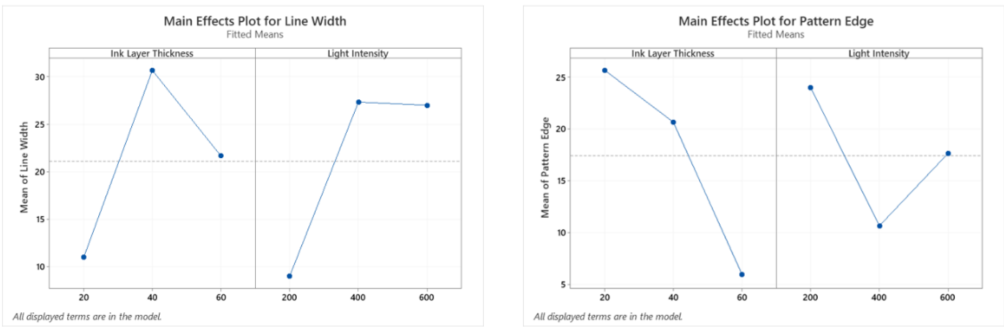
Since both curing temperature and the curing time parameters show significant results, another two parameters have been analyzed: ink layer thickness and light source intensity. Figure 6 (a) shows that factor A and factor B do not cross near the red dotted lines at 44% confidence level, which means these parameters are insignificant for line width response. Meanwhile, Figure 6 (b) shows the Pareto chart in which the pattern edge has allotted as the response shows the same result at 47% confidence level. Thus, both factors are also insignificant to the pattern edge response.



(a) (b)

Figure 5: Pareto chart for ink layer thickness and light intensity on (a) line width (b) pattern edge

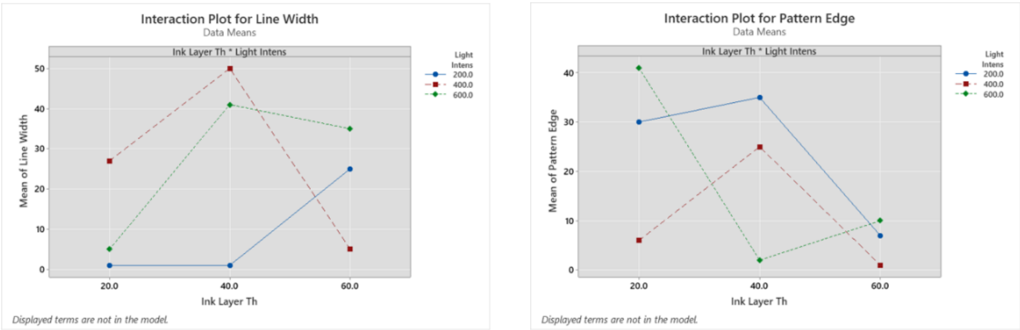
The main effects plots help visualize which factors most affect the response as each level factor affects the responses differently. For example, Figure 7 (a) depicts the ink layer thickness of 40 μm, and the light source intensity of 400 mW/cm^2 has a high impact on line width response. Meanwhile, 20 μm and 200 mW/cm^2, the least impact on line width response.



(a) (b)

Figure 6: Main effects plot for ink layer thickness and light source intensity (a) line width (b) pattern edge

Furthermore, in the interaction plot from Figure 8 (a) and 8 (b), the lines are not parallel, which means an interaction effect between ink layer thickness and response values depends on the light source's intensity. However, none of the linear is equivalent to the significance level as their p-value is> 0.1 [10]. Since some parameters show significant and insignificant results, the parameters are still important in this study. Curing temperature and curing time are selected as input parameters as it shows significant result while ink layer thickness and light source intensity are set as a constant parameter.

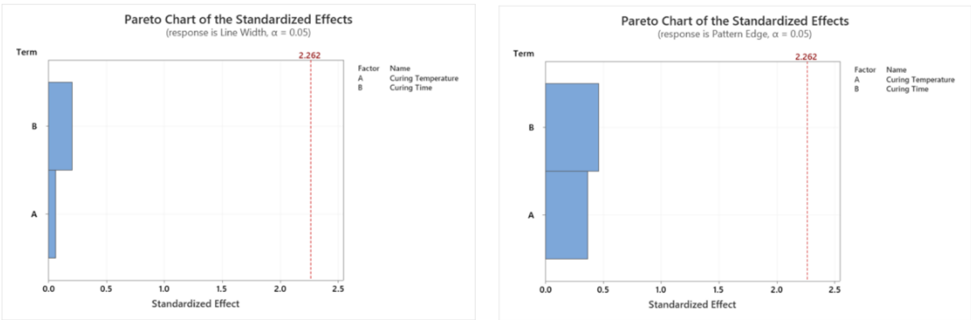


(a) (b)

Figure 7: Interaction plot for ink layer thickness and light source intensity (a) line width (b) pattern edge

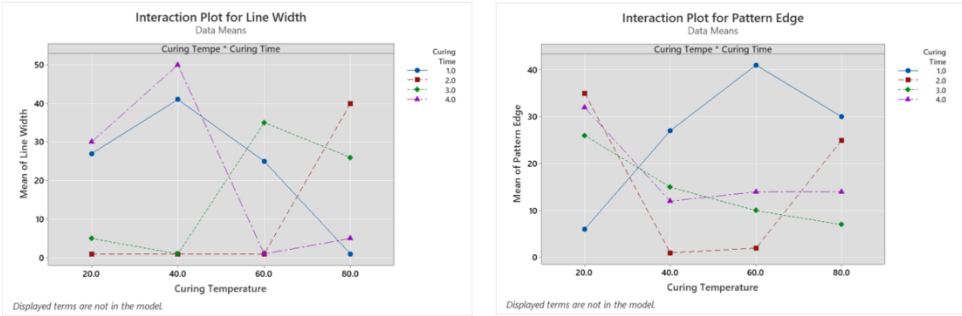
3.2 Result of Simulation: Selection of significance level of curing parameters

First, 4-level designs of the full factorial method were simulated with two selected curing parameters: curing temperature and curing time correspond to line width and pattern edge as response value. Figures 9 (a) and 9 (b) show that factor A and factor B do not cross near the red dotted lines. It is proven these parameters are insignificant to 4-level designs with 16 trials run even though there is an interaction between both parameters in Figures 10 (a) and 10 (b) with the response value yet, the results are still difficult to interpret [9]. Besides, with more trials of run, experiments become very complex and costly. Therefore, 3-level designs with 9 trials are selected as the optimum level for curing PVC synthetic leather substrates. Finding results on this level design under subtopic 3.1.



(a) (b)

Figure 8: Pareto chart for curing temperature and curing time with 4 level (a) line width (b) pattern edge



(a) (b)

Figure 9: Interaction plot of curing temperature and curing time with 4 level (a) line width (b) pattern edge

3.3 Result of Experiment

The primary purpose of this actual experiment is to give a clear picture of the behaviour of this study and compare whether the significant levels for each curing parameter proposed, as listed in Table 3, is adequate for the curing process whilst verifying the optimum value of curing parameters. To begin, 16 samples were examined using Minitab software at 4-level designs and two different curing parameters: curing temperature and curing time. These samples indicate insignificant results for this study. Hence, the number of samples was reduced to 9 samples at 3-level designs and the same parameters to yield significant results on response parameters. However, the actual experiment and measurement and testing are not being conducted in this study due to the COVID-19 pandemic. Furthermore, due to the national lockdown, Movement Control Order (MCO), all public higher education institutions (IPTA) are being told to close to prevent sporadic cases.

Table 3: Result of experiment

Trial no	Curing temperature (°C)	Curing time (VSD)	Smear test (smear/not smear)	Adhesion level (0B – 5B)	CYMK level
1		2	N/A	N/A	N/A
2	50	3	N/A	N/A	N/A
3		4	N/A	N/A	N/A
4		2	N/A	N/A	N/A
5	60	3	N/A	N/A	N/A
6		4	N/A	N/A	N/A
7		2	N/A	N/A	N/A
8	70	3	N/A	N/A	N/A
9		4	N/A	N/A	N/A

4. Conclusion

In conclusion, the study's objective is achieved where the study is to determine the suitable variation and optimum curing parameters to cure the ink properly on synthetic leather. However, another study's objective, which is to investigate the feasibility of existing curing techniques for the curing process on synthetic leather, is not achieved due to the COVID-19 pandemic as no actual experiments were conducted. Further study is still required; hence, other students will verify the simulation results obtained from Minitab software.

Based on the findings in this study, a full factorial method was selected for the simulation process to determine the suitable curing parameters to properly cure the ink on PVC synthetic leather substrates.

As a result, four main curing parameters were identified, including curing temperature, curing time, ink layer thickness and the light source intensity. Simulation analysis using Minitab proves that ink layer thickness and the light source intensity must be kept constant. Both show insignificant results instead of curing temperature and curing time which is the most convincing parameter corresponding to line width and pattern edge response value. Furthermore, 3-level designs with 9 trials run were selected as the optimum level for curing temperature at 50°C, 60°C, 70°C, and curing time at VSD_2, VSD_3 and VSD_4, for curing the PVC synthetic leather substrates

Overall, this study also highlighted three elements of sustainable development: social equity, economic growth, and environmental protection, which focused on finding strategies to promote economic and social advancement in ways that avoid environmental degradation, over-exploitation, and pollution in curing synthetic leather substrates.

Last but not least, to have a clear picture of the curing process on PVC synthetic leather substrates, as it is a new study that is yet to be explored, a few recommendations can be implemented for future work. This including by using another tool analysis such as the response surface method (RSM) to analyze curvature in the data and select the best factor settings.

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