Research Progress in Mechanical and Manufacturing Engineering Vol. 3 No. 1 (2022) 623-631

RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Optimization of Curing Process Significant Parameter and Level via Simulation on Curing of Printed Pattern on Synthetic Leather Substrate

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DOI: https://doi.org/10.30880/rpmme.2022.03.01.065
Received 15 Nov. 2021; Accepted 15 April 2022; Available online 30 July 2022

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, from clothing such as jackets and skirts to accessories like belts, wallets, handbags, and even shoes. Ultraviolet printing (UV) has shown great potential in synthetic leather printing with good speed and quality. However, some drawbacks were found, including graphical structure easily cracked, the UV ink is not fully cured, causing material remains sticky or wet and giving an unpleasant odour causing some health problems due to over exposure to UV light. Therefore, research is required to resolve such issues based on the direct printing technique using eco-solvent ink and existing curing technique used. In this study, a simulation was conducted via Minitab software to characterise and optimise the significant and level of curing parameters to cure the ink properly for printing process on synthetic leather substrate. This contribution evaluates the optimum level for both the significant and level of input parameters correspond to line width and pattern edge response values. Four parameters, were identified for curing process including curing temperature, curing time, ink layer thickness and light source intensity. The obtained results show only curing temperature and curing time are significant with 3-level design for curing the synthetic leather substrates at 50°C, 60°C, 70°C, and at VSD_2, VSD_3 and VSD_4 respectively.

Keywords: Curing, Synthetic Leather, Simulation

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

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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.

Today, it can seem 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 [5] and is more like to cause skin damage and health problems [6].

Hence, previous studies have found that synthetic leather was the best option for printing substrate since it gives more benefits than real leather. Along with eco-solvent ink and inkjet printing technology, both provide a greener alternative, less expensive, easier to manufacture and care for than real leather. The investigation of using eco-solvent with the established printing should be conducted as this study is important whether the simulation using Minitab software (Full Factorial Method) can characterize and optimize significant and factor levels of printing and curing parameters as the time of trial and run can be reduced and can increase productivity and quality.

The overarching aims of the study were twofold: (a) to characterize and optimize significant curing parameters: curing temperature, curing time, ink layer thickness and light source intensity via simulation on curing printed pattern synthetic leather substrate; (b) to determine the significant factor levels of curing parameters: 4-level or 3-level design via simulation on curing printed pattern the synthetic leather substrate.

2. Materials and Methods

Before starting a curing process, a printing process must consider the pattern design onto the substrate to check the quality of appearance and printed images based on line width and pattern edges. There are two types of pattern design, such as simple and intricate pattern design. The proposed printed design substrate is shown in Figure 1.

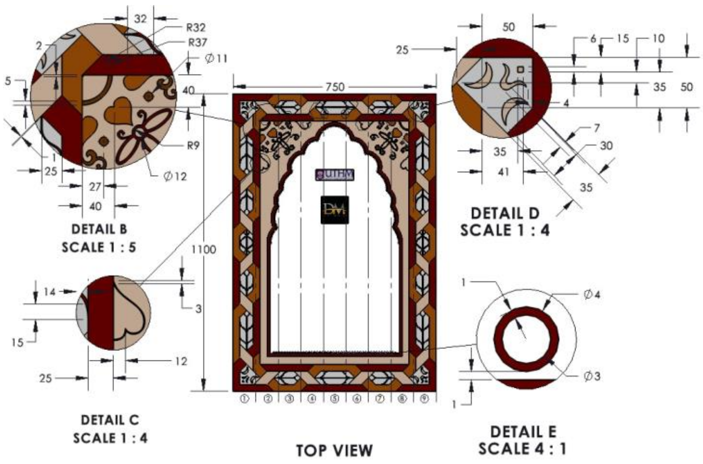


Figure 1: Simple and intricate pattern design on PVC synthetic leather substrates

As illustrated in Figure 2, before performing the experiment, appropriate curing parameters are identified as these procedures are used to set a significant level of each parameter in the printing and curing process. Once identified, it is then characterized into input parameters such as curing temperature, curing time, ink layer thickness and light source intensity; meanwhile, a response parameter is taken as line width and pattern edge of design substrates as its need for finding out the influence of the input parameters on it. These design factors have a crucial role to play in order for the substrates to be fully cured. Then, proceed with an identification of significant levels of curing parameters using Full Factorial Method. It can be 4-level or 3-level design using Minitab software to analyze all those significant levels for curing parameters. If the significant levels for curing parameters meet the criteria, it is applicable in conducting a curing process on synthetic leather material.

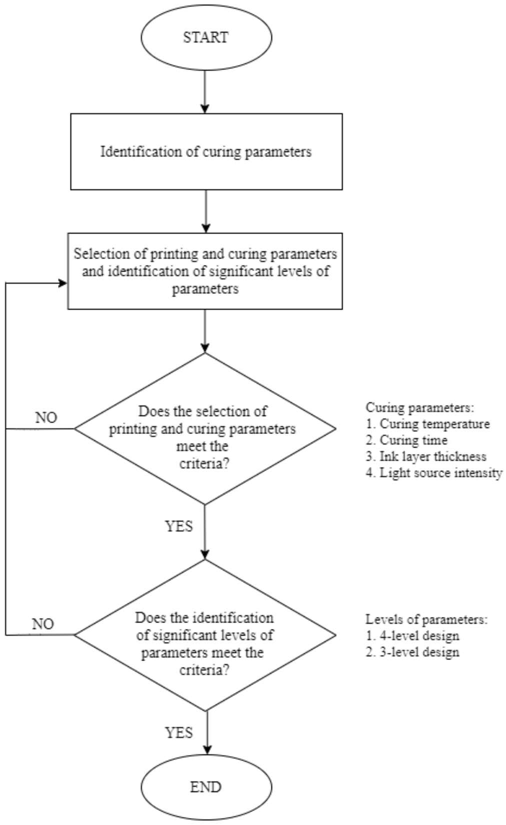


Figure 2: Flowchart

3. Results and Discussion

3.1 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. Meanwhile, as tabulated in Table 2, the response parameters, including line width and pattern edge, were randomly taken from the SolidWorks drawing.

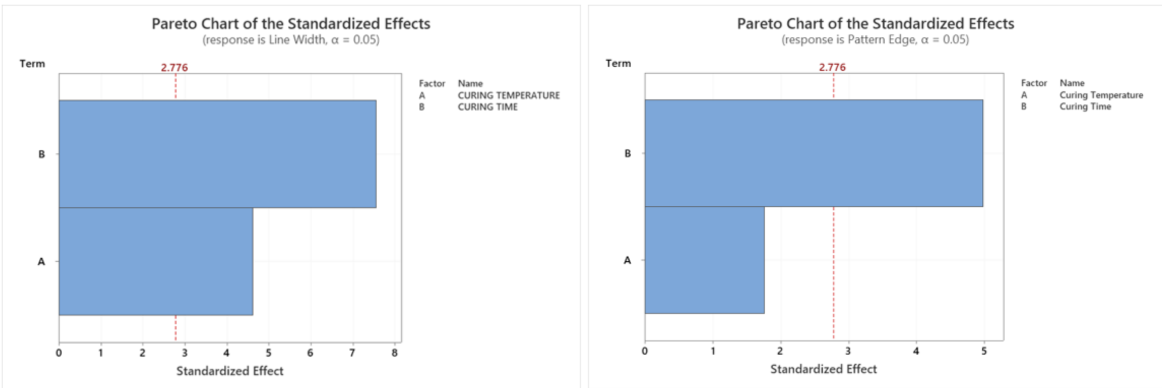
Table 1: Table of input curing parameters and the values set

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 values set

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

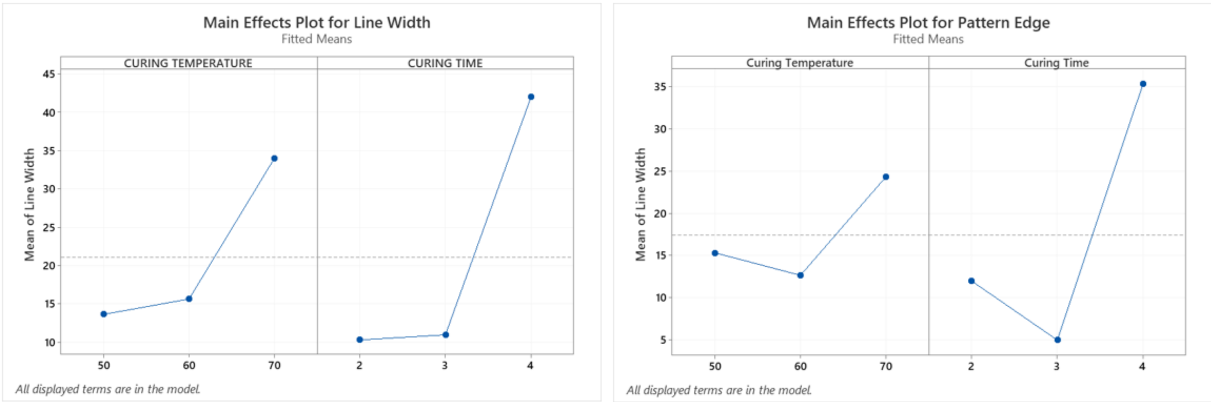
Figure 3 (a) shows the Pareto chart of curing temperature and curing time with line width as a response value. The factors A and B crossing the red dotted line showing that these factors are significant at a 97% confidence level. Any effects that extend beyond the reference line are significant [7]. 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 [8].



(a) (b)

Figure 3: Pareto chart for curing temperature and curing time on (a) line width (b) pattern edge

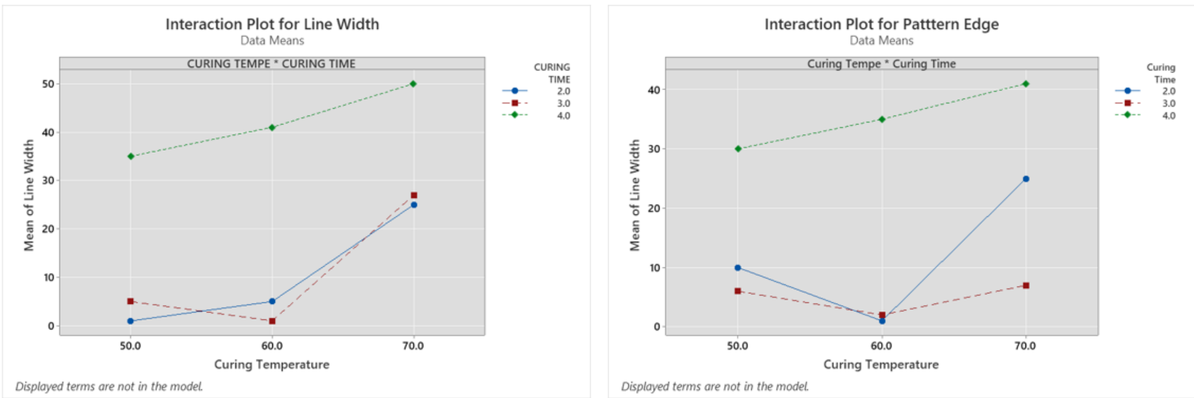
This can also be supported through the Main effects plot. One can observe and validate that curing parameters in the highest value is significant through Figure 4 (a) and 4 (b) graphically shows the same trend at the most convincing parameters. A longer curing time have an adverse effect and provides more energy to strengthen the polymerization of the ink particles on prints substrate [9].



(a) (b)

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

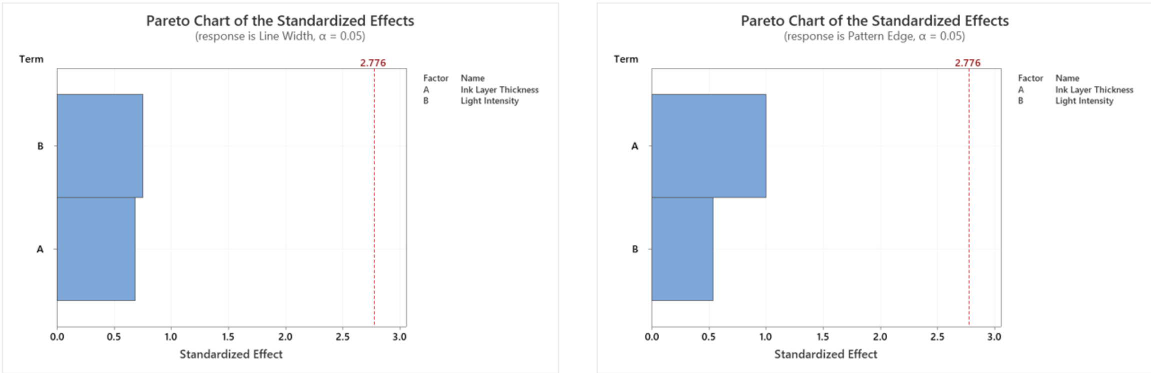
Other than that, when the interaction at a factor level is dependent on the levels of other factors, the interaction exists since it can diminish the main effects of the parameters [8]. The interaction plot from Figure 5 (a) and 5 (b), shows more nonparallel lines, which there is stronger interaction between input and response parameters [10]. 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 [8]



(a) (b)

Figure 5: Interaction plot for curing temperature and curing time on (a) line width (b) pattern edge

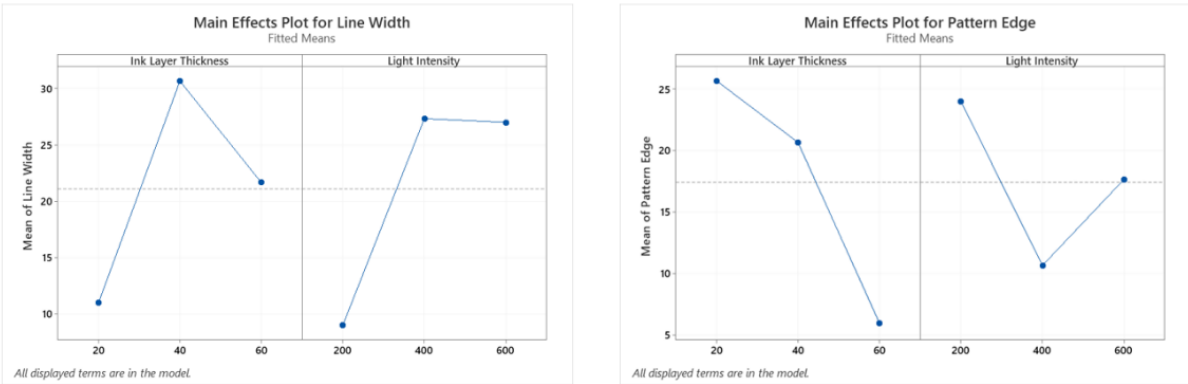
Since both curing temperature and the curing time parameters show significant results, another two parameters have been analyzed: ink layer thickness and light source intensity. Figure 6 (a) shows that factor A and factor B do not cross near the red dotted lines at 44% confidence level, which means these 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 6: Pareto chart for ink layer thickness and light intensity on (a) line width (b) pattern edge

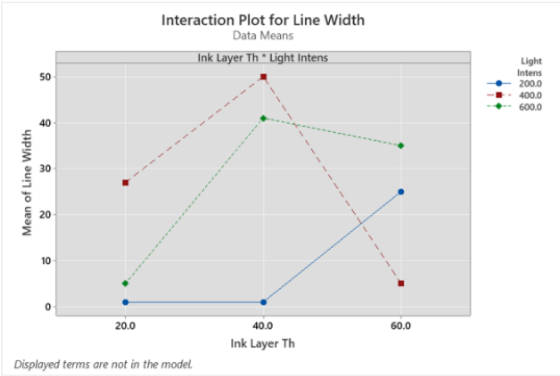
The main effects plots help visualize which factors most affect the response as each level factor affects the responses differently. For example, Figure 7 (a) depicts the ink layer thickness of 40 μm, and the light source intensity of 400 mW/cm^2 has a high impact on line width response. Meanwhile, 20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



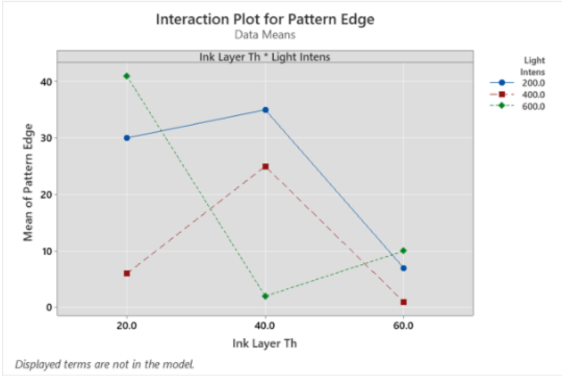
(a) (b)

Figure 7: 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 [8]. 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)

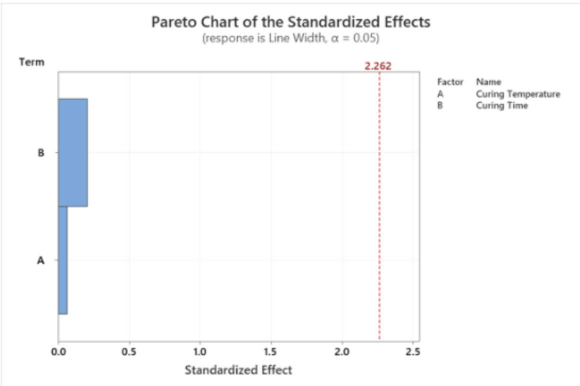


(b)

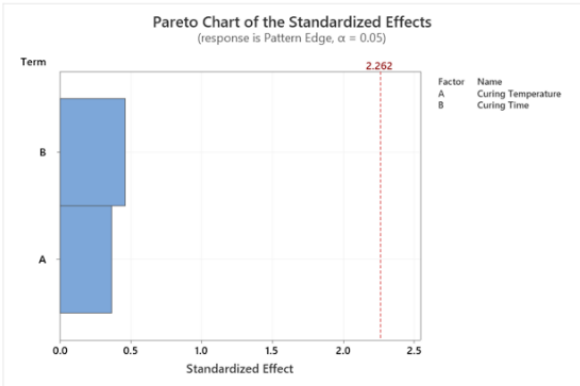
Figure 8: Interaction plot for ink layer thickness and light source intensity (a) line width (b) pattern edge

3.2 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 [7]. 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.

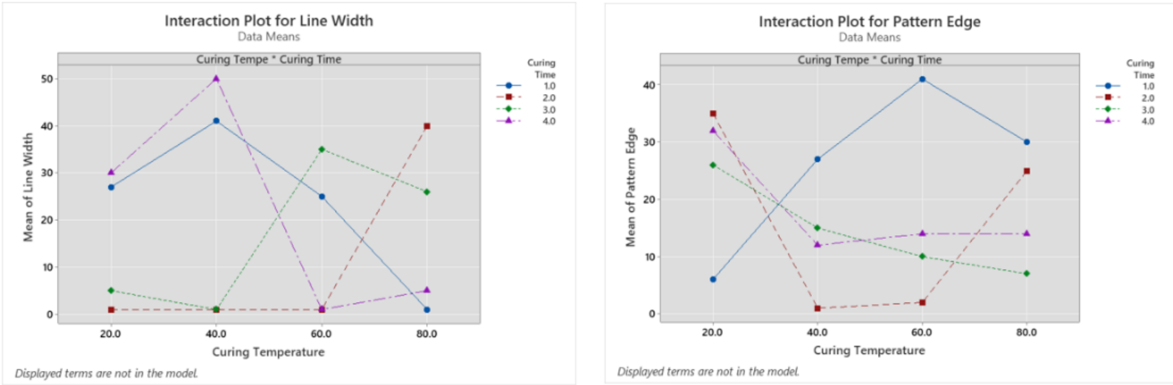


(a)



(b)

Figure 9: Pareto chart for curing temperature and curing time with 4 level (a) line width (b) pattern edge



(a) (b)

Figure 10: Interaction plot of curing temperature and curing time with 4 level (a) line width (b) pattern edge

4. Conclusion

In conclusion, the objectives in this study are achieved: (a) to characterize and optimize significant curing parameters: curing temperature, curing time, ink layer thickness and light source intensity via simulation on curing printed pattern synthetic leather substrate and (b) to determine the significant factor levels of curing parameters: 4-level or 3-level design via simulation on curing printed pattern synthetic leather substrate. This is because, 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 could be kept constant for ease of experimental purposes. 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. Further study is required based on actual experiments such as verifying the simulation results obtained from Minitab software.

Acknowledgement

The authors wish to thank to the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia that has supported on the accomplishment of research activity.

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