Optimisation of the Sublimation Textile Printing Process Using the Taguchi Method

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Abstract
In this paper, printing parameters for the sublimation printing of polyester fabrics like the number of strokes, the sublimation paper weight in grams per square metre, the fusing temperature and time were optimised using the Taguchi experimental design technique. In the evaluations the signal-to-noise ratio was used. Sixteen experiments were performed with respect to the L 16 Orthogonal array design for the Taguchi approach. The results show a considerable improvement in the signal-to-noise ratio as compared to the initial conditions. Through this study, not only can optimum printing conditions for sublimation printed polyester fabrics be obtained but also the significant factors that affect water vapour resistance.

Key words: knitted fabrics, sublimation printing, experimental design, Taguchi design, water vapour resistance.

Introduction
Textile printing can be defined as the process of transferring ink to a textile substrate using a specific printing technique. Digital ink jet textile printing offers a higher printing speed of short runs, as well as flexibility, creativity and environment safety. It is important to note that using the digital printing technique enables better visual effects, as well as no limitation of print formats [1-3]. Besides that, it is easier to get unified print quality during production runs. Another advantage of digital ink jet is the ability of printing on a great number of different substrates. One of the fabrics most often used for digital printing is polyester fabric because of characteristics like thermal stability, excellent behaviour during exploitation and uniform quality. For the printing of polyester or polyester mix fabrics, the textile industry has long been using sublimation printing. Recently, digital ink-jet printing has opened completely new possibilities as well as competitive advantages [4, 5]. The quality of sublimation printed textile fabrics depends on factors like the number of strokes, sublimation paper GSM, the fusing temperature and duration. As the number of strokes increases, ink deposition on the sublimation paper increases, resulting in increased colour transformation by compromising the comfort properties. Similarly, variation in the sublimation paper weight in grams per square metre, as well as in the fusing temperature and time affects the colour transformation and water vapour resistance of printed goods. Hence, there is a need to find optimum printing conditions which ultimately enhance the quality but with less interference with the wearer’s comfort. These four factors have a varying effect on the colour transformation and water vapour resistance characteristics. There are various approaches to optimize the problems in engineering, one of which being Taguchi’s method.

Taguchi methodology
Taguchi methodology for optimisation can be divided into four phases: planning, conducting, analysis and validation. Each phase has a separate objective and contributes towards the overall optimisation process. The primary goal is to keep the variance in the output very low, even in the presence of noise inputs. Thus, the processes or products are made robust against all variations. Taguchi’s methods focus on the effective application of engineering strategies rather than advanced statistical techniques [6-8]. Taguchi views the design of a product or process as a three-phase program:

1. System design: This phase deals with innovative research. Here, one looks for what each factor and its level should be rather than how to combine many factors to obtain the best result in the selected domain.

2. Parameter design: The purpose of parameter design is to investigate the overall variation caused by inner and outer noise when the levels of the control factors are allowed to vary widely. Quality improvement is achievable without incurring much additional cost. This strategy is obviously well suited to the production floor.

3. Tolerance design: This phase must be preceded by parameter design activities. This is used to determine the best tolerances for the parameters [9-11].

Two major tools used in the Taguchi method are the orthogonal array (OA) and the signal-to-noise ratio (SNR or S/N ratio). Orthogonal array (OA) is a matrix of numbers arranged in rows and columns.

Materials and methods
100% Polyester fabric knitted with a single jersey structure was selected for this experiment. The fabrics were procured from the manufacturer with the characteristics shown in Table 1. The fabrics were subjected to washing treatment to remove the presence of impurities and then to sublimation printing varying the number of strokes, the sublimation pa-
per grams per square metre, the fusing temperature and time. The effects of the treatment of the water vapour resistance of printed fabrics were studied. The printing parameters were optimised using the Tauguchi approach. The control parameters were selected as the number of strokes, sublimation paper GSM, fusing temperature and duration. The surface morphology of the polyester fabrics was observed under a scanning electron microscope (SEM ZESS Instrument).

**Table 1. Fabric’s characteristics.**

| Fabric type       | Courses/cm | Wales/cm | Stitch density/square cm | Thickness, mm |
|-------------------|------------|----------|--------------------------|---------------|
| 100% Polyester    | 18         | 14       | 252                      | 48            |
| Single Jersey     |            |          |                          |               |

**Table 2. Printing parameters and levels.**

| Factors                     | Designation | Level 1 | Level 2 | Level 3 | Level 4 |
|-----------------------------|-------------|---------|---------|---------|---------|
| Number of strokes           | S           | 2       | 3       | 4       | 5       |
| Sublimation paper GSM       | W           | 20      | 50      | 80      | 100     |
| Fusing temperature, °C      | T           | 160     | 170     | 180     | 190     |
| Fusing duration, s          | D           | 45      | 50      | 55      | 60      |

**Table 3. Experimental layout using L16 modified array.**

| Trial order | S | W | T | D |
|-------------|---|---|---|---|
| 1           | 1 | 1 | 1 | 1 |
| 2           | 2 | 2 | 2 | 2 |
| 3           | 3 | 3 | 3 | 3 |
| 4           | 4 | 4 | 4 | 4 |
| 5           | 5 | 5 | 5 | 5 |
| 6           | 6 | 6 | 6 | 6 |
| 7           | 7 | 7 | 7 | 7 |
| 8           | 8 | 8 | 8 | 8 |
| 9           | 9 | 9 | 9 | 9 |
| 10          | 10| 10| 10| 10|
| 11          | 11| 11| 11| 11|
| 12          | 12| 12| 12| 12|
| 13          | 13| 13| 13| 13|
| 14          | 14| 14| 14| 14|
| 15          | 15| 15| 15| 15|
| 16          | 16| 16| 16| 16|

**Table 4. Measured values of water vapour resistance and resulting SNR.**

| Trial | S | W | T | D | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | Mean | SNR |
|-------|---|---|---|---|----|----|----|----|----|----|----|----|----|------|-----|
| 1     | 2 | 57| 190|45 | 6.376|6.372|6.638|6.390|6.362|6.374|6.380|6.390|6.386|6.40978|-16.1376|
| 2     | 3 | 67| 195|50 | 6.454|6.450|6.616|6.480|6.458|6.454|6.456|6.458|6.458|6.45978|-16.2044|
| 3     | 4 | 74| 200|55 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 4     | 5 | 94| 205|60 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 5     | 6 | 74| 200|60 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 6     | 7 | 57| 205|55 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 7     | 8 | 74| 200|60 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 8     | 9 | 57| 195|45 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 9     | 10| 74| 200|50 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 10    | 11| 57| 205|55 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 11    | 12| 74| 200|50 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 12    | 13| 57| 205|55 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 13    | 14| 74| 200|50 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 14    | 15| 57| 205|55 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|
| 15    | 16| 74| 200|50 | 6.526|6.522|6.743|6.568|6.525|6.523|6.520|6.529|6.528|6.52544|-16.6850|

**Water-vapour resistance (Rw)**

In the sublimation printing process, an ink layer is transferred onto the fabrics, where part of the printed ink covers the surface of the garment, while the other part of the ink fills the pores between fibres. Thereby, the printed ink represents a new material layer, i.e. an additional barrier to heat transfer from the body’s surface to the environment. The research presented investigates the influence of this new material layer created by the printing process on the water vapour resistance characteristics of the fabrics as well as on the water-vapour pressure difference between the two faces of the material divided by the resultant evaporative heat flux per unit area in the direction of the gradient. It is a quantity specific to textile materials or composites which determines the “latent” evaporative heat flux across a given area in response to a steadily applied water-vapour pressure gradient. The evaporative heat flux may consist of both diffusive and convective components. Water-vapour resistance is expressed in square metres pascal per watt as per ISO 11092:2014 using the sweating guarded hot plate test [17-19].

### Experimental design

**Table 2** gives various parameters and their level with designations. The response variable, namely the water vapour resistance, was measured.

### Results and discussion

The experimental lay-out using an L16 orthogonal array is shown in **Table 3**. In order to save time and printing costs, Tauguchi’s method was adopted. Ex-
Experiments were carried out according to the combination of levels indicated in Table 3 for four different levels. An orthogonal array helps in determining the number of trials that are necessary and the factor levels for each parameter. A general L16 orthogonal array consists of a combination of experiments with four factors each at four levels.

**Main effect plots**

After performing the experiments as per Taguchi’s experimental design, a main effects plot was made for the ultimate water vapour resistance of the printed fabrics, which ultimately decides the comfort of the printed fabrics. The lower the resistance the better the fabric comfort without compromising the colour transformation. The results obtained from experimentation are shown in Table 4. The typical response of Minitab is shown in Table 5 and 6.

**Signal/Noise ratio**

Taguchi suggests that the response values at each inner array design point be summarised by a performance criterion called the signal-to-noise ratio. The S/N ratio is expressed in decibels (dB). Conceptually, the S/N ratio (\( \eta \)) is the ratio of signal to noise in terms of power. Another way to look at it is that it represents the ratio of sensitivity to variability. The higher the SNR, the better the quality of the product [15, 16]. The idea is to maximise the SNR, thereby minimising the effect of random noise factors, which have a significant impact on the process performance. Therefore, the method of calculating the S/N ratio depends on whether the quality characteristic is smaller-the-better, larger-the-better, or nominal-the-best [12-14].

Lower is better (water vapour resistance).

\[
S/N = -10 \log \left( \frac{1}{n} \sum_{i=1}^{n} y_i^2 \right) \tag{1}
\]

Where \( n \) is the number of experiments in the orthogonal array and \( y_i \) the \( i \)th value measured.

Where \( y \) is the average of data observed and \( s^2 \) the variation.

The S/N ratio plots are shown in Figures 1 and 2.

**Effect of printing parameters on the response variable**

From Figure 3 we can observe that an increase in the number of strokes causes the mean water vapour resistance to increase for 57 GSM; a similar trend is observed for 67, 74 and 94 GSM. The lowest mean water vapour resistance is observed at a number of strokes equal to 2 for 67 sublimation paper GSM. From Figure 4 we can observe that a fusing temperature of 205 degrees celsius with 50 seconds fusing considerably reduces the water vapour resistance.

**Interaction plots**

Contour plots are plotted for the water vapour resistance response variable against sublimation printing parameters at different levels using Minitab. In Figure 5 contour plots are plotted for ultimate sublimation paper GSM and numbers of strokes against water vapour resistance. Similarly, contour plots are plotted for the fusing temperature and

![Figure 1. Main effects plots for WVR means.](image1)

![Figure 2. Main effects plots for SN ratios of WVR.](image2)

![Figure 3. Effect of number of strokes on WVR.](image3)

![Figure 4. Effect of fusing temperature on WVR.](image4)
fusing time against water vapour resistance (Figure 6).

From Table 7 the optimisation of printing parameters is arrived at. For factor (S), with a number of strokes equal to 2, with 74 GSM sublimation paper, with a temperature of 205 degrees celsius and a 50 sec fusing time, the optimum effect on water vapour resistance can be achieved.

Scanning electron microscopy of the printed fabrics shown in Figure 7 under normal printing conditions and optimum printing parameter conditions reveal that sublimation printed polyester fabrics show the entrapment of more ink on their surface. The printing parameters under optimum conditions derived using the Taguchi approach enhance the print colour quality and reduce the water vapour resistance, which are essential parameters for polyester fabrics meant for technical and industrial applications [20-25].

### Conclusions

In this research, we intended to create a process for optimising sublimation printing conditions using the Taguchi design to minimise the water vapour resistance of knitted fabrics. We can conclude from this research that by using the Taguchi design, we can determine the optimal variables. Based on the S/N ratio, optimum levels of the various parameters are obtained. As a result of the Taguchi method, the quality of a product is improved by minimising the effect of the causes of variation without eliminating them. In this methodology, the design desired is finalised by selecting the best performance under conditions that produce a consistent performance. The Taguchi approach provides systematic, simple and efficient methodology for the optimisation of near optimum design parameters with only a few well-defined experimental sets and determines the main factors affecting the process. From Tauguchi analysis of the minimum water vapour resistance using the response of means and response of S/N ratios, the predominant factors influencing the quality of sublimation printed single jersey knitted fabrics are the number of strokes of printing on the transfer paper. The minimum water vapour resistance of printed fabrics can be achieved. namely with a number of strokes equal to 2, 74 GSM sublimation paper, a temperature of 205 degrees celsius, and a 50 sec fusing time. From this research work parameter optimisation and factors influencing the response can be well predicted. There is a huge saving of cost and time by minimising the consumption of inks, fusing energy and fusing time.
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References

1. Fukazawa T, Kawamura Y, Tochihara Y, Tamura T. Water Vapour Transport Through Textiles and Condensation in Clothes at High Altitudes - Combined Influence of Temperature and Pressure Simulating Altitude. Text. Res. J. 2003; 73 (8): 657-663.
2. Dehghani A, Jahanshah F, Borman D, Dennis K. Wang J. Design and Engineering Challenges for Digital Ink-Jet Printing on Textiles. International Journal of Clothing Science and Technology 2004; 16: 262-273.
3. Yuen C, Ko S, Choi P, Kan CW. Study of the Factors Influencing Colour Yield of an Ink-Jet Printed Cotton Fabric. Coloration Technology 2004; 120: 320-325.
4. Choi PSR, Yuen CWM, Ku SKA, Kan CW. Digital Ink-jet Printing for Chitosan -treated Cotton Fabric. Fibers and Polymers 2005; 6, 3: 229-235.
5. Owen P. Digital Printing: A World of Opportunity from Design to Production. AATCC Review 2003; 3, 9: 10-15.
6. Park CK, Ha JY. A Process for Optimizing Sewing Conditions to Minimize Seam Pucker Using the Taguchi Method. Textile Research Journal 2005; 75(3): 245-252.
7. Palanikumar K. Cutting Parameters Optimization for Surface Roughness in Machining of GFRP Composites Using Taguchi’s Method. Journal of Reinforced Plastics and Composites 2006; 25, 16: 1739-1751.
8. Ishtiaque SM, Salhotra KR. Study of Effect of Spinning Process Variables on the Packing Density of Ring, Rotor and Air-Jet Yarns Using the Taguchi Method. Autex Research Journal 2006; 6, 3: 122-135.
9. Kumar A, Ishtiaque SM, Salhotra KR. Analysis of Spinning Process Using the Taguchi Method. Part IV: Effect of Spinning Process Variables on Tensile Properties of Ring, Rotor and Air-Jet Yarns. Journal of the Textile Institute 2006; 97, 5: 385-390.
10. SSAlhotra KR, Ishtiaque SM, Kumar A. Analysis of Spinning Process Using the Taguchi Method. Part I: Effect of Spinning Process Variables on Fibre Orientation and Tenacities of Silver and Roving. Journal of the Textile Institute 2006; 97, 4: 271-284.
11. Cheng JC, Lai WT, Chou CY, Lin HH. Determination of Sizing Conditions for E-Glass Fibre Yarn Using Taguchi Parameter Design. Materials Science and Technology 2007; 23, 6: 683-687.
12. Brojeswari Das, Das A, Kothari! VK, Fangueiro R, de Araújo M. Moisture Transmission Through Textiles-Part II: Evaluation Methods And Mathematical Modelling. AUTEX Research Journal 2007; 7, 3: 194-216.
13. Yang K, Jiao M L, Chen Y-S, Li J, Zhang W-Y. Analysis and Prediction of Dynamic Heat-Moisture Comfort Property of Fabric. FIBRES & TEXTILES in Eastern Europe 2008; 16, (368): 51-55.
14. Zeydan M. Modelling the Woven Fabric Strength Using Artificial Neural Network and Taguchi Methodologies. International Journal of Clothing Science and Technology 2008; 20, 2: 104-118.
15. Mavruz S, Ogulata RT. Taguchi Approach for the Optimisation of the Bursting Strength of Knitted Fabrics. FIBRES & TEXTILES in Eastern Europe 2010, 18, 2(79): 78-83.
16. Kašiković N, Novaković D, Karlović I, Vidić G. Influence of Ink Layers on the Quality of Ink Jet-printed Textile Materials. Tekstil i konfekcija 2012; 22, 2: 115-120.
17. ISO 11092:2014. Textiles – Physiological effects – Measurement of thermal and water-vapour resistance under steady-state conditions (swelling guarded-hotplate test) (Geneva: ISO, 2014).
18. Huang J. Review of Heat and Water Vapour Transfer Through Multilayer Fabrics. Textile Research Journal 2016; 86(3): 325-336.
19. Mladen Stancic, Nemanja Kasikovic, Dragana Grujic, Dragoljub Novakovic, Rastko Milosevic Milosevic, Branka Ruzicic, Jelka Gersak. Mathematical Model for Water Vapour Resistance Prediction of Printed Garments, Society of Dyers and Colourists. Color. Technol. 2017; 134: 82-88.
20. Kazani I, de Mey G, Hertleer C, van Langenhove L, Guoxo G. Influence of Screen Printed Layers on the Thermal Conductivity of Textile Fabrics. FIBRES & TEXTILES in Eastern Europe 2018; 26, 5(131): 70-74. DOI: 10.5604/01.3001.0012.2534.
21. Eldbee M, Demir A. Optimising the Production Process of Rieter Air Jet Spun Yarns and a Model for Prediction of their Strength. FIBRES & TEXTILES in Eastern Europe 2018; 26, 1(127): 36-41. DOI: 10.5604/01.3001.0010.7794.
22. Plonka S, Dobrina R, Jędrzejczyk D, Pstrożny J. Selection of Optimal Thermo-chemical Treatment of Steel Guides of Yarn. FIBRES & TEXTILES in Eastern Europe 2019; 27, 6(138): 27-33. DOI: 10.5604/01.3001.0013.4464.
23. Hong C, Chen S. Optimisation of Multi-Response Surface Parameters of the Roving Twist Factor and Spinning Back Zone Draft. FIBRES & TEXTILES in Eastern Europe 2019; 27, 5(137): 28-33. DOI: 10.5604/01.3001.0013.2698.
24. Unal C, Yüksel AO. Cut Order Planning Optimisation in the Apparel Industry. FIBRES & TEXTILES in Eastern Europe 2020; 28, 1(139): 8-13. DOI: 10.5604/01.3001.0013.5851.
25. Pruš S, Kulpiński P, Matyjas-Zgondek E. Changes in the Specific Charge Amount on the Surface of Cotton Fibres during the Alkali Pre-treatment Process. FIBRES & TEXTILES in Eastern Europe 2019; 27, 4(136): 30-37. DOI: 10.5604/01.3001.0013.1817.
