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Scientific article

Optimization of flexographic process parameters using taguchi's grey relational analysis technique

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Abstract: *This paper is an experimental and statistical approach to find out an optimal solution for the high print quality reproducible by flexographic printing on coated and uncoated substrate using Taguchi's Grey Relational Analysis method. The halftone image composed of round and square shaped dots with AM screening and the anilox roller with three different screen rulings are employed at different trial runs of experiment. Total of 12 numbers of experimental runs with different combinations of paper grades, halftone dot shapes and anilox roller rulings are employed in the experiment to investigate its influence on the final print quality. The print quality evaluation is based on the assessment of Optical Ink Density (solid areas), Dot Gain, Hue Error and Print Contrast using Taguchi's Grey Relational Analysis method. Based on the Taguchi's GRA score, the optimal solution for the high print quality is prioritized. This paper aims to distinguish the influence of substrate, halftone dot shape and anilox cell ruling in the final print quality of flexographic process. Also, it demonstrates the scope of applying Taguchi's Grey Relational Analysis in the printing field to find out an optimal solution for the multiple criteria-based decision-making activities.*

Keywords: *Optical Ink Density, Dot Gain, Hue Error, Print Contrast, Taguchi's GRA method.*

1. Introduction

Flexography is a roll-to-roll relief printing technique which utilizes liquid ink and flexible photopolymer or rubber printing plate to deliver quality image onto a wide variety of substrates such as paper, paperboard, plastic films, foils, laminations etc. [1]. Figure 1 shows the schematic diagram of flexographic printing unit.

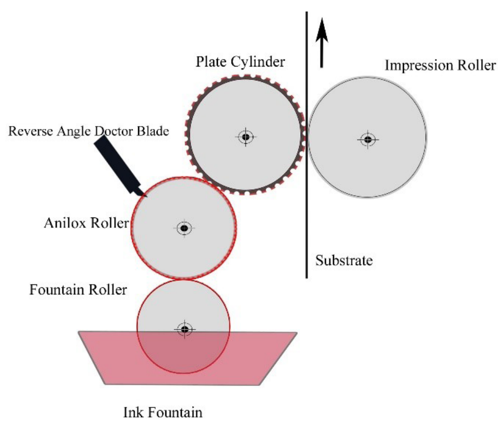

Figure 1 *Schematic diagram of flexographic printing unit: the well metered ink from the surface of anilox roller is transferring on to the flexographic plate and then to the substrate.*

The flexographic printing technology employs anilox roller inking system and it acts as the fundamental part of the printing unit for efficient transmitting and metering of ink from the ink fountain to the printing plate. The characteristics of cells engraved on the surface of anilox roller determine the quantity of ink to be supplied to the printing plate. So, the quality of flexographic print ultimately depends on the surface properties of the anilox roller. Figure 2 shows the schematic diagram of anilox roller.

Figure 2 *: Schematic diagram of anilox roller [2]: the characteristics of tiny engraved cells over the anilox roller will determine the quantity of ink to be transferred on to the flexographic image carrier in printing.*

The remarkable distinctiveness of flexographic printing technique to deliver quality image onto a wide variety of surfaces makes it as a suitable printing technique for a wide application like: commercial printing, packaging, publication printing etc. Nowadays, the key part of the printing paper related to the packaging applications are carried out by flexographic printing process because of its excellence in printability together with cost-effective nature when compared to other printing techniques. Various researches and studies are going in the industry and academic institutions to investigate more into the factors related to the flexographic printing process.

Genichi Taguchi, Japanese engineer and statistician introduced the Taguchi method in the 1950's which can be statistically useful to improve the quality of output in variety of manufacturing applications. The Taguchi method of quality control approach is effective to eradicate variances occurs in the production process before its occurrence [3].

Grey Relational Analysis (GRA) is a method to find out the degree of correlation of variables associated with a process and it is developed by Deng Julong in 1982. The Grey Relational Grade will give indication on the degree of correlation between the actual performance in relation to the target performance [4]. GRA method is better to solve multiple conditions based decision making activities. The Taguchi based GRA model is a better solution to the various field of manufacturing process in engineering like-quality control, optimization etc. [5]. The primary goal of the Taguchi approach is to create dependable systems which can withstand unpredictable circumstances. The Taguchi's technique optimizes the design parameters also called control variables, so that the system response is sturdy—that is, immune to noise sources, which are difficult or impossible to manage. The concept of application of Taguchi model in flexographic printing gives comparable results with another model like box behnken model [6].

In the flexographic printing process, the anilox ruling frequency is varied from the finer to coarser screen frequency to get the final image to be printed well. The anilox roller cells are responsible to carry the required amount of ink into the printing unit to print the each and every halftone dot properly as per the requirements of printing. The anilox cell size opening smaller than that of the minimum dot size of halftone to be printed will bring better print result in flexography. The

Dot Gain issues may increase by increasing the plate image screen frequency and decreasing cell count of anilox roller [7].

The flexographic printing has some limitations to handle shadow areas and finer dots in highlight areas in the reproduction by using solitary AM screening. Although, the FM screening method in highlight and shadow will bring better result than AM [8]. The technique adopting FM-AM hybrid technology with flexography will brighten the situation as well. This technique employs, FM screening method in both highlight as well as shadow areas and AM screening method on rest of the tonal areas of the image [9]. This can eliminate the tonal transmission deficiencies in the printing in terms of better highlight details, smoother gradient, exact tonal value reproduction etc. [10]. The use of FM dots at 0% to 10%, AM dots at 10% to 75% and FM dots again at 75% to 100% in the tonal areas of a graphic reproduction on substrate like PVC can empower flexographic print quality to an optimum level [11].

The halftone dot deformation can cause irregularities in print quality, including a sudden increase in the tone value or loss of highlight tones. The increase in dot coverage may be occur due to the wear of the polymer plate, which caused the side shoulders of the dot to become a part of the printing surface. The correct ratio of the anilox roller line screen to the line ruling of the printing plate is important in order to ensure a minimum dot size in print [12].

The printability and print quality of flexographic printing is dependent on the surface smoothness of the substrate. The ink absorption and spreading are influenced by the surface texture of substrate. The elastic deformation tendency of printing plate at high pressure leads to unpredictable dot deformation and ink spread [13].

The Dot Gain or Tonal Value Increase (TVI) indicates the increase of dot size in the final print than that of the original dot size given at the input. The Print Contrast indicates the accuracy of halftone reproduction at the shadow areas of a print [14]. The assessment of Print Contrast at 70% or 75% tonal areas are the most common practice followed in the industry. The Hue Error indicates the shift in the real hue of the ink that is printed on the substrate. It may occur mainly due to the contamination of ink at the press condition, or the optical behaviour associated with the substrate, viewing conditions etc. Hue Error monitors the quality of the printing ink and thus measures the purity of ink in terms of percentage of deviation of the printed colour compared to the actual hue required. The inaccuracy in the reproduction of actual hue and inaccurate colour strength at various tonal regions will be the result related with the hue error. The three process colours are Cyan, Magenta and Yellow. Hue Error is calculated to quantify and regulate the level of impurity in printing inks [15].

The most popular and effective way to get the high print quality is to coordinate with the ISO 12647-6 standard's objective values. However, a specific combination of ink, anilox roller, printing plates, printing substrates, and printing machine determines how the production process is characterised. As a result, there are no suitable characterisation implementation methods that would consider each of these factors and specify the precise values for every potential combination. Therefore, it is critical that the set of qualitative data or the process characterization should match with the expectations of the customers. The rapid growth of the flexographic industry with innovative technological solutions in every aspect of the production process makes it impossible to create a suitable standard [16].

In the present paper the effects of anilox roller screen frequency on the print quality along with effect of paper surface are taken into consideration. The shapes of the dot patterns and its correlation with anilox screen ruling frequency are also considered. Taguchi's GRA is used to find out the optimum requirement of the input to get the desired print.

2. Materials and Methods

The experiment was conducted by printing an ideal grey-scale step wedge of dot coverage varying from 5% to 100% with both AM Square and AM Round dot onto two grades of substrates were Coated Paper and Uncoated paper. As the anilox roller acts as the core of flexographic printing process to deliver exact print quality, three different kinds of anilox roller rulings were 700 CPI (275.6 c/cm), 1000 CPI (393.7 c/cm) and 1300 CPI (Cells Per Inch) (511.8 c/cm) (Cells Per Centimeter) were employed to obtain. The engraved cells chosen for the paper features 60º hexagonal in geometry. The printing paper executed in Flexographic printing machine, OMET LAB230 Iflex (Printing speed – 35 m/min, Nip pressure – 3 mm) with Black colour UV ink. The plate used is photopolymer plate of 1.14 mm thickness with magnetic backing.

Each element of the specified samples of printed sheets are subjected to visual analysis with a Digital Microscope (LEICA, S8APO) followed by the quantitative optical property measurement using Spectro Densitometer (X-Rite Spectro Eye and TECHKON GmbH Spectro Dens). The collected data were systematically processed and the print quality assessment was carried out by concentrating onto some major print parameters were Optical Ink Density, Hue Error, Dot Gain and Print Contrast.

In the computation process, 30%, 50% and 70% (that represents highlight, middle-tone and shadow areas respectively) step-wedges are targeted for the analysis of Dot Gain, Hue Error and the Print Contrast.

Considering the experimental variable parameters are substrate, dot shape and anilox ruling and the quality assessment parameters are Optical Ink Density, Dot Gain, Hue Error and the Print Contrast, the Taguchi's Orthogonal Array for Grey Relational Analysis was performed.

Figure 3 shows flow chart of the process adopted to optimize the parameters to obtain print as per requirement.

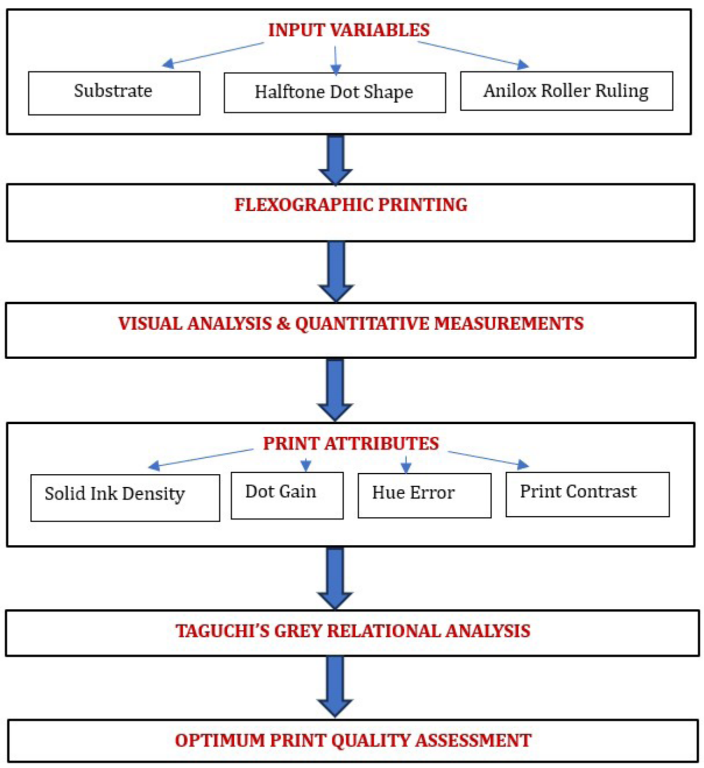

Figure 3 *Paper Flow: the sequential flow of various stages of this research paper*

Specifications of the two chosen printing substrates:

Uncoated paper (white), grammage 83.96 g/m2, opacity 100.5%, whiteness 244.99.
Coated paper (white), grammage 153.41 g/m2, opacity 100.67%, whiteness 213.3.
Printing plate specifications:
Type of plate – Digital solid photopolymer
Manufacturer of the printing plate – Dupont
Plate thickness – 1.14 mm
Anilox roller specifications:
Shape of cells – 600 hexagonal
Volume of cells – BCM 4.1 (700 CPI), BCM 3.9 (1000 CPI), BCM 3.8 (1300 CPI)
Distortion factor – 1.3%
Same mounting tape - Yes

The Table 1 shows the experimental variables and the quality assessment parameters taken for the Taguchi's GRA Relational Analysis.

Table 1 *Elements of Performance Index Array for Taguchi's Grey Relational Analysis*

Experiment No	Experimental variables	Factors
1	Coated Paper-Round Dot-700 CPI Anilox	Optical Ink Density Dot Gain Hue Error Print Contrast
2	Coated Paper-Round Dot-1000 CPI Anilox	
3	Coated Paper-Round Dot-1300 CPI Anilox	
4	Uncoated Paper-Round Dot-700 CPI Anilox	
5	Uncoated Paper-Round Dot-1000 CPI Anilox	
6	Uncoated Paper-Round Dot-1300 CPI Anilox	
7	Coated Paper-Square Dot-700 CPI Anilox	
8	Coated Paper-Square Dot-1000 CPI Anilox	
9	Coated Paper-Square Dot-1300 CPI Anilox	
10	Uncoated Paper-Square Dot-700 CPI Anilox	
11	Uncoated Paper-Square Dot-1000 CPI Anilox	
12	Uncoated Paper-Square Dot-1300 CPI Anilox	

2.1 Taguchi's Grey Relational Analysis Method

2.1.1 Normalization of Performance Index Data

For beneficial attributes (higher is better),

$$Xi^*(k) = \frac{Xi^*(k) \text{ - } \min Xi\ (k)}{\max Xi(k) \text{ - } \min Xi\ (k)} \tag{1}$$

For non-beneficial attributes (lower is better),

$$Xi^*(k) = \frac{\max Xi(k) \text{ - } Xi\ (k)}{\max Xi(k) \text{ - } \min Xi\ (k)} \tag{2}$$

where,

$Xi^*(k)$=Normalized value of ith data of ‘k’ responses.
$Xi(k)$ = Actual value of ith data of ‘k’ responses.
$min\ Xi^*(k)$ =Lowest value of for ‘k’ responses.
$max\ Xi^*(k)$ =Highest value of for ‘k’ responses.

2.1.2 Deviation Sequence

$$\Delta i(k) = X_0^m(k) - Xi^*(k) \tag{3}$$

where,

$\Delta i(k)$ =*Deviation sequence of ith data for ‘k’ responses.*
$X_0^m(k)$ = Maximum value among the elements of ‘k’ responses.
$Xi^*(k)$ = Normalized value of performance index of ‘k’ responses.

2.1.3 Grey Relational Co-efficient

$$\mathcal{E}i(k) = \frac{\Delta min + \mathcal{E}\Delta \max}{\Delta i(k) + \mathcal{E}\Delta \max} \tag{4}$$

where,

$\mathcal{E}i(k)$ = Grey Relational Co-efficient of i^{th} data for ‘k’ responses.
Δmin= Minimum value obtained from Deviation sequence.
Δmax= Maximum value obtained from Deviation sequence.
$\Delta i(k)$ =Deviation sequence of i^{th} data for ‘k’ responses.
Dynamic Distinguished Coefficient ($\mathcal{E}$) = 0-1
(For multiple decision-making criteria, the value can take as 0.5).

2.1.4 Grey Relational Grade

$$Yi = \frac{1}{n}\sum_{k=1}^{n} \mathcal{E}i(k) \tag{5}$$

where,

Yi = Grey Relational Grade of ith data for ‘k’ responses.
n= Number of data responses
$\mathcal{E}i(k)$ = Grey Relational Co-efficient of ith data for ‘k’ responses.

2.2. Hue Error

$$\text{Hue Error} = \frac{D_M - D_L}{D_H - D_L} \; x\ 100 \tag{6}$$

where,

DH=Highest Optical Ink Density
DM=Medium Optical Ink Density
DL=Lowest Optical Ink Density

2.3. Print Contrast

$$\text{Print Contrast} = \frac{D_S - D_T}{D_S} \; x\ 100 \tag{7}$$

where,

D_S = Optical Ink Density (solid areas)
D_T = Optical Ink Density (tinted areas)

3. Results

The optical properties of the prints obtained under different conditions are measured using X-Rite Spectro Eye (Optical Ink Density, Hue Error, Dot Gain and Print Contrast) and TECHKON GmbH SpectroDens (Opacity, Whiteness) and the optical data plotted are shown vide Figures 4-7.
Figure 4 shows the Tonal Reproduction Curve of the prints under different conditions.
Figure 5 shows the variations in Dot Gain at different dot percentage of the original under different conditions.
Figure 6 shows the variations in Hue Errors of the prints at different dot percentages of dot areas.
Figure 7 shows the variations of Print Contrast of the different prints at different percentage of dot area of the original.

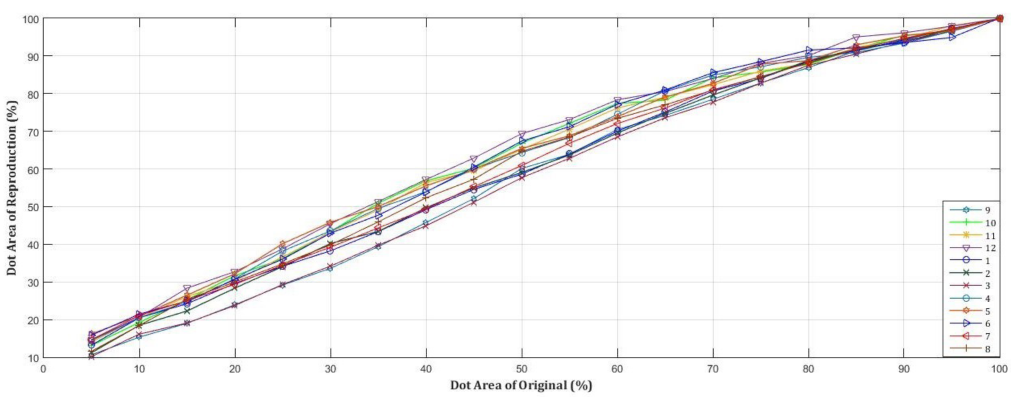

***Figure 4** Tonal Reproduction Curve for Dot Area*

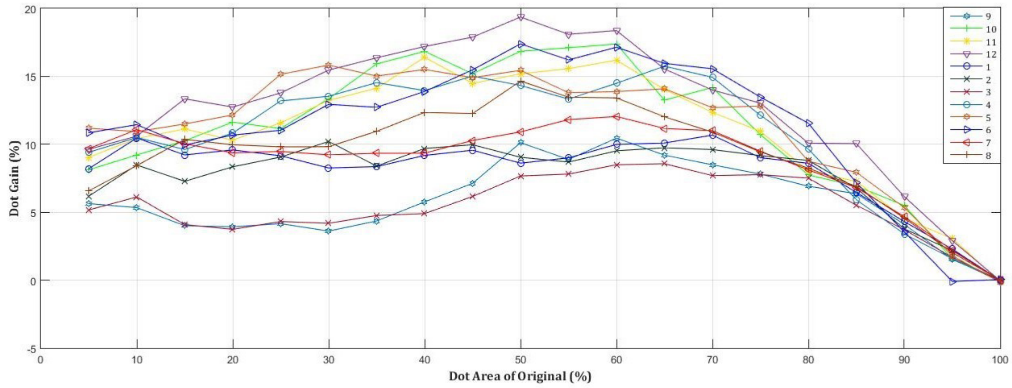

Figure 5 *Variation in Dot Gain with respect to percentage Dot Area of the original*

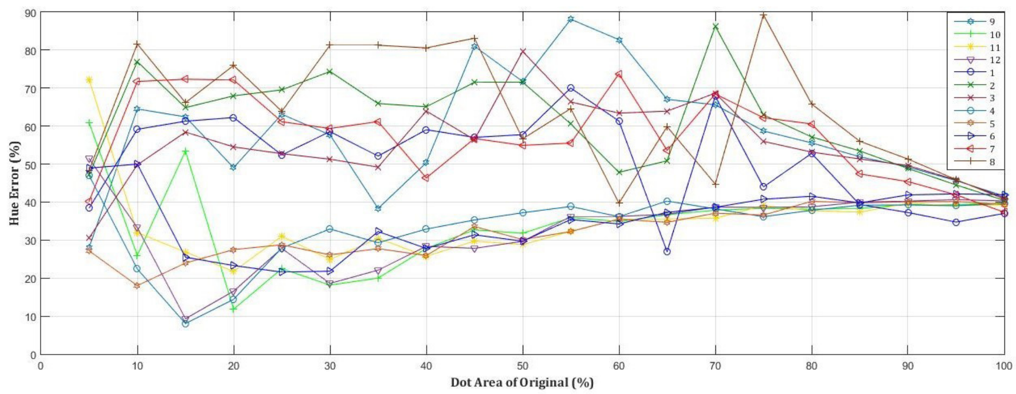

Figure 6 *Variation in Hue Error with percentage Dot Area of the original*

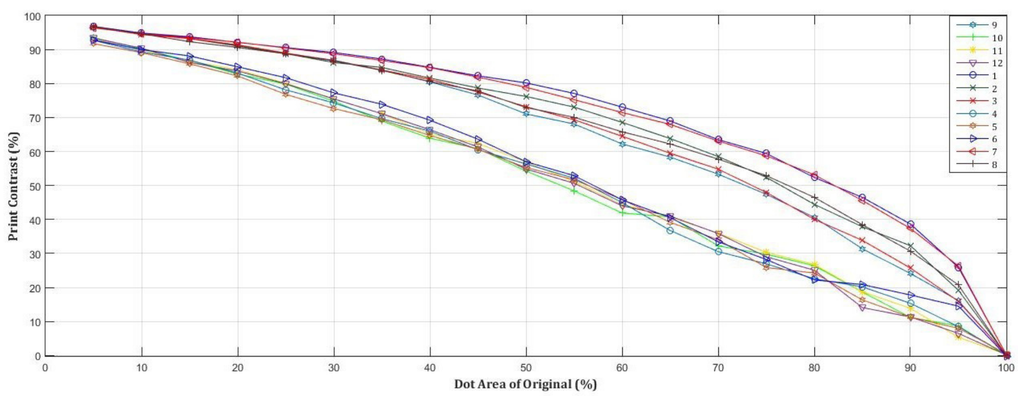

Figure 7 *Variation in Print Contrast with reference to percentage Dot Area of the original*

Taguchi's Grey Relational Analysis for the collected data are carried out and the Grey Relational Grade is calculated. As per the Grade the test prints are prioritized under ranking based on different parameters such as Optical Ink Density, Dot Gain, Hue Error and Print Contrast.
The various stages of Taguchi's Grey Relational Analysis process are tabulated as- Normalization (Table 2), Deviation Sequence (Table 3), Grey Relational Coefficient (Table 4).

Table 2 *Normalised Table of Performance Index*

Exp. No.	Optical Ink Density	Dot Gain at 30%	Dot Gain at 50%	Dot Gain at 70%	Hue Error at 30%	Hue Error at 50%	Hue Error at 70%	Print Contrast at 30%	Print Contrast at 50%	Print Contrast at 70%
1	1.00	0.70	0.90	0.64	0.36	0.43	0.37	1.00	1.00	1.00
2	0.71	0.54	0.82	0.76	0.11	0.16	0.00	0.82	0.84	0.85
3	0.47	1.00	1.00	1.00	0.48	0.00	0.35	0.85	0.74	0.74
4	0.00	0.19	0.37	0.04	0.77	0.84	0.96	0.10	0.07	0.00
5	0.00	0.00	0.29	0.36	0.88	0.98	0.98	0.00	0.05	0.12
6	0.13	0.27	0.11	0.00	0.94	0.98	0.95	0.29	0.11	0.09
7	1.00	0.57	0.69	0.61	0.35	0.49	0.35	0.97	0.95	0.99
8	0.74	0.53	0.41	0.62	0.00	0.45	0.83	0.84	0.73	0.83
9	0.45	0.98	0.74	0.89	0.37	0.16	0.41	0.84	0.64	0.69
10	0.02	0.24	0.20	0.18	1.00	0.94	0.96	0.14	0.00	0.04
11	0.05	0.25	0.32	0.48	0.90	1.00	1.00	0.18	0.09	0.18
12	0.13	0.06	0.00	0.24	1.00	0.99	0.94	0.17	0.02	0.16

Table 3 *Deviation Sequence*

Exp. No.	Optical Ink Density	Dot Gain at 30%	Dot Gain at 50%	Dot Gain at 70%	Hue Error at 30%	Hue Error at 50%	Hue Error at 70%	Print Contrast at 30%	Print Contrast at 50%	Print Contrast at 70%
1	0.00	0.30	0.10	0.36	0.64	0.57	0.63	0.00	0.00	0.00
2	0.29	0.46	0.18	0.24	0.89	0.84	1.00	0.18	0.16	0.15
3	0.53	0.00	0.00	0.00	0.52	1.00	0.65	0.15	0.26	0.26
4	1.00	0.81	0.63	0.96	0.23	0.16	0.04	0.90	0.93	1.00
5	1.00	1.00	0.71	0.64	0.12	0.02	0.02	1.00	0.95	0.88
6	0.87	0.73	0.89	1.00	0.06	0.02	0.05	0.71	0.89	0.91
7	0.00	0.43	0.31	0.39	0.65	0.51	0.65	0.03	0.05	0.01
8	0.26	0.47	0.59	0.38	1.00	0.55	0.17	0.16	0.27	0.17
9	0.55	0.02	0.26	0.11	0.63	0.84	0.59	0.16	0.36	0.31
10	0.98	0.76	0.80	0.82	0.00	0.06	0.04	0.86	1.00	0.96
11	0.95	0.75	0.68	0.52	0.10	0.00	0.00	0.82	0.91	0.82
12	0.87	0.94	1.00	0.76	0.00	0.01	0.06	0.83	0.98	0.84

***Table 4** Grey Relational Coefficient*

Exp. No.	Optical Ink Density	Dot Gain at 30%	Dot Gain at 50%	Dot Gain at 70%	Hue Error at 30%	Hue Error at 50%	Hue Error at 70%	Print Contrast at 30%	Print Contrast at 50%	Print Contrast at 70%
1	1.00	0.63	0.83	0.58	0.44	0.47	0.44	1.00	1.00	1.00
2	0.63	0.52	0.73	0.68	0.36	0.37	0.33	0.74	0.76	0.77
3	0.48	1.00	1.00	1.00	0.49	0.33	0.43	0.77	0.66	0.66
4	0.33	0.38	0.44	0.34	0.68	0.76	0.93	0.36	0.35	0.33
5	0.33	0.33	0.41	0.44	0.80	0.96	0.96	0.33	0.34	0.36
6	0.36	0.41	0.36	0.33	0.90	0.96	0.90	0.41	0.36	0.36
7	1.00	0.54	0.62	0.56	0.43	0.49	0.44	0.94	0.90	0.98
8	0.66	0.51	0.46	0.57	0.33	0.48	0.74	0.76	0.65	0.74
9	0.48	0.96	0.66	0.81	0.44	0.37	0.46	0.75	0.58	0.62
10	0.34	0.40	0.38	0.38	1.00	0.89	0.93	0.37	0.33	0.34
11	0.35	0.40	0.42	0.49	0.83	1.00	1.00	0.38	0.36	0.38
12	0.37	0.35	0.33	0.40	1.00	0.97	0.89	0.38	0.34	0.37

Based on the Grey Relational Co-efficient, the Grey Relational Grading and Ranking of experiments are given in the Table 5-15. According to Taguchi's Grey Relational Analysis, the highest value of Grey Relational Grade that indicates the better performance.

***Table 5** The Grey Relational Grade and Ranking for Optical Ink Density*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Coated Paper-Round Dot-700 CPI Anilox	1.000	1
2	Coated Paper-Square Dot-700 CPI Anilox	1.000	7
3	Coated Paper-Square Dot-1000 CPI Anilox	0.657	8
4	Coated Paper-Round Dot-1000 CPI Anilox	0.632	2
5	Coated Paper-Round Dot-1300 CPI Anilox	0.483	3
6	Coated Paper-Square Dot-1300 CPI Anilox	0.475	9
7	Uncoated Paper-Square Dot-1300 CPI Anilox	0.365	12
8	Uncoated Paper-Round Dot-1300 CPI Anilox	0.364	6
9	Uncoated Paper-Square Dot-1000 CPI Anilox	0.345	11
10	Uncoated Paper-Square Dot-700 CPI Anilox	0.338	10
11	Uncoated Paper-Round Dot-1000 CPI Anilox	0.334	5
12	Uncoated Paper-Round Dot-700 CPI Anilox	0.333	4

Table 6 *The Grey Relational Grade and Ranking for 30% Dot Gain*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Coated Paper-Round Dot-1300 CPI Anilox	1.000	3
2	Coated Paper-Square Dot-1300 CPI Anilox	0.957	9
3	Coated Paper-Round Dot-700 CPI Anilox	0.627	1
4	Coated Paper-Square Dot-700 CPI Anilox	0.537	7
5	Coated Paper-Round Dot-1000 CPI Anilox	0.521	2
6	Coated Paper-Square Dot-1000 CPI Anilox	0.515	8
7	Uncoated Paper-Round Dot-1300 CPI Anilox	0.407	6
8	Uncoated Paper-Square Dot-1000 CPI Anilox	0.401	11
9	Uncoated Paper-Square Dot-700 CPI Anilox	0.397	10
10	Uncoated Paper-Round Dot-700 CPI Anilox	0.381	4
11	Uncoated Paper-Square Dot-1300 CPI Anilox	0.348	12
12	Uncoated Paper-Round Dot-1000 CPI Anilox	0.333	5

Table *7 The Grey Relational Grade and Ranking for 50% Dot Gain*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Coated Paper-Round Dot-1300 CPI Anilox	1.000	3
2	Coated Paper-Round Dot-700 CPI Anilox	0.827	1
3	Coated Paper-Round Dot-1000 CPI Anilox	0.731	2
4	Coated Paper-Square Dot-1300 CPI Anilox	0.656	9
5	Coated Paper-Square Dot-700 CPI Anilox	0.616	7
6	Coated Paper-Square Dot-1000 CPI Anilox	0.459	8
7	Uncoated Paper-Round Dot-700 CPI Anilox	0.443	4
8	Uncoated Paper-Square Dot-1000 CPI Anilox	0.423	11
9	Uncoated Paper-Round Dot-1000 CPI Anilox	0.414	5
10	Uncoated Paper-Square Dot-700 CPI Anilox	0.384	10
11	Uncoated Paper-Round Dot-1300 CPI Anilox	0.359	6
12	Uncoated Paper-Square Dot-1300 CPI Anilox	0.333	12

Table 8 *The Grey Relational Grade and Ranking for 70% Dot Gain*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Coated Paper-Round Dot-1300 CPI Anilox	1.000	3
2	Coated Paper-Round Dot-700 CPI Anilox	0.827	1
3	Coated Paper-Round Dot-1000 CPI Anilox	0.731	2
4	Coated Paper-Square Dot-1300 CPI Anilox	0.656	9
5	Coated Paper-Square Dot-700 CPI Anilox	0.616	7
6	Coated Paper-Square Dot-1000 CPI Anilox	0.459	8
7	Uncoated Paper-Round Dot-700 CPI Anilox	0.443	4
8	Uncoated Paper-Square Dot-1000 CPI Anilox	0.423	11
9	Uncoated Paper-Round Dot-1000 CPI Anilox	0.414	5
10	Uncoated Paper-Square Dot-700 CPI Anilox	0.384	10
11	Uncoated Paper-Round Dot-1300 CPI Anilox	0.359	6
12	Uncoated Paper-Square Dot-1300 CPI Anilox	0.333	12

Table 9 *The Grey Relational Grade and Ranking for 30% Hue Error*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Uncoated Paper-Square Dot-700 CPI Anilox	1.000	10
2	Uncoated Paper-Square Dot-1300 CPI Anilox	1.000	12
3	Uncoated Paper-Round Dot-1300 CPI Anilox	0.896	6
4	Uncoated Paper-Square Dot-1000 CPI Anilox	0.832	11
5	Uncoated Paper-Round Dot-1000 CPI Anilox	0.804	5
6	Uncoated Paper-Round Dot-700 CPI Anilox	0.682	4
7	Coated Paper-Round Dot-1300 CPI Anilox	0.488	3
8	Coated Paper-Square Dot-1300 CPI Anilox	0.444	9
9	Coated Paper-Round Dot-700 CPI Anilox	0.439	1
10	Coated Paper-Square Dot-700 CPI Anilox	0.434	7
11	Coated Paper-Round Dot-1000 CPI Anilox	0.360	2
12	Coated Paper-Square Dot-1000 CPI Anilox	0.333	8

Table 10 *The Grey Relational Grade and Ranking for 50% Hue Error*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Uncoated Paper-Square Dot-1000 CPI Anilox	1.000	11
2	Uncoated Paper-Square Dot-1300 CPI Anilox	0.974	12
3	Uncoated Paper-Round Dot-1000 CPI Anilox	0.962	5
4	Uncoated Paper-Round Dot-1300 CPI Anilox	0.962	6
5	Uncoated Paper-Square Dot-700 CPI Anilox	0.894	10
6	Uncoated Paper-Round Dot-700 CPI Anilox	0.760	4
7	Coated Paper-Square Dot-700 CPI Anilox	0.494	7
8	Coated Paper-Square Dot-1000 CPI Anilox	0.478	8
9	Coated Paper-Round Dot-700 CPI Anilox	0.468	1
10	Coated Paper-Round Dot-1000 CPI Anilox	0.373	2
11	Coated Paper-Square Dot-1300 CPI Anilox	0.372	9
12	Coated Paper-Round Dot-1300 CPI Anilox	0.333	3

Table 10 *The Grey Relational Grade and Ranking for 70% Hue Error*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Uncoated Paper-Square Dot-1000 CPI Anilox	1.000	11
2	Uncoated Paper-Round Dot-1000 CPI Anilox	0.962	5
3	Uncoated Paper-Round Dot-700 CPI Anilox	0.926	4
4	Uncoated Paper-Square Dot-700 CPI Anilox	0.926	10
5	Uncoated Paper-Round Dot-1300 CPI Anilox	0.904	6
6	Uncoated Paper-Square Dot-1300 CPI Anilox	0.893	12
7	Coated Paper-Square Dot-1000 CPI Anilox	0.742	8
8	Coated Paper-Square Dot-1300 CPI Anilox	0.459	9
9	Coated Paper-Round Dot-700 CPI Anilox	0.441	1
10	Coated Paper-Square Dot-700 CPI Anilox	0.437	7
11	Coated Paper-Round Dot-1300 CPI Anilox	0.435	3
12	Coated Paper-Round Dot-1000 CPI Anilox	0.333	2

Table 12 *The Grey Relational Grade and Ranking for 30% Print Contrast*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Coated Paper-Round Dot-700 CPI Anilox	1.000	1
2	Coated Paper-Square Dot-700 CPI Anilox	0.939	7
3	Coated Paper-Round Dot-1300 CPI Anilox	0.768	3
4	Coated Paper-Square Dot-1000 CPI Anilox	0.762	8
5	Coated Paper-Square Dot-1300 CPI Anilox	0.753	9
6	Coated Paper-Round Dot-1000 CPI Anilox	0.739	2
7	Uncoated Paper-Round Dot-1300 CPI Anilox	0.413	6
8	Uncoated Paper-Square Dot-1000 CPI Anilox	0.379	11
9	Uncoated Paper-Square Dot-1300 CPI Anilox	0.377	12
10	Uncoated Paper-Square Dot-700 CPI Anilox	0.367	10
11	Uncoated Paper-Round Dot-700 CPI Anilox	0.357	4
12	Uncoated Paper-Round Dot-1000 CPI Anilox	0.333	5

Table 13 *The Grey Relational Grade and Ranking for 50% Print Contrast*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Coated Paper-Round Dot-700 CPI Anilox	1.000	1
2	Coated Paper-Square Dot-700 CPI Anilox	0.901	7
3	Coated Paper-Round Dot-1000 CPI Anilox	0.756	2
4	Coated Paper-Round Dot-1300 CPI Anilox	0.658	3
5	Coated Paper-Square Dot-1000 CPI Anilox	0.646	8
6	Coated Paper-Square Dot-1300 CPI Anilox	0.584	9
7	Uncoated Paper-Round Dot-1300 CPI Anilox	0.360	6
8	Uncoated Paper-Square Dot-1000 CPI Anilox	0.356	11
9	Uncoated Paper-Round Dot-700 CPI Anilox	0.350	4
10	Uncoated Paper-Round Dot-1000 CPI Anilox	0.344	5
11	Uncoated Paper-Square Dot-1300 CPI Anilox	0.338	12
12	Uncoated Paper-Square Dot-700 CPI Anilox	0.333	10

Table 14 *The Grey Relational Grade and Ranking for 70% Print Contrast*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Coated Paper-Round Dot-700 CPI Anilox	1.000	1
2	Coated Paper-Square Dot-700 CPI Anilox	0.975	7
3	Coated Paper-Round Dot-1000 CPI Anilox	0.765	2
4	Coated Paper-Square Dot-1000 CPI Anilox	0.743	8
5	Coated Paper-Round Dot-1300 CPI Anilox	0.659	3
6	Coated Paper-Square Dot-1300 CPI Anilox	0.615	9
7	Uncoated Paper-Square Dot-1000 CPI Anilox	0.380	11
8	Uncoated Paper-Square Dot-1300 CPI Anilox	0.374	12
9	Uncoated Paper-Round Dot-1000 CPI Anilox	0.361	5
10	Uncoated Paper-Round Dot-1300 CPI Anilox	0.355	6
11	Uncoated Paper-Square Dot-700 CPI Anilox	0.343	10
12	Uncoated Paper-Round Dot-700 CPI Anilox	0.333	4

Table 16 *The Overall Grey Relational Grade and Ranking*

Rank	Experimental variables	Grey Relational Grade	Experiment No.
1	Coated Paper-Round Dot-700 CPI Anilox	0.738	1
2	Coated Paper-Square Dot-700 CPI Anilox	0.689	7
3	Coated Paper-Round Dot-1300 CPI Anilox	0.682	3
4	Coated Paper-Square Dot-1300 CPI Anilox	0.613	9
5	Coated Paper-Square Dot-1000 CPI Anilox	0.590	8
6	Coated Paper-Round Dot-1000 CPI Anilox	0.589	2
7	Uncoated Paper-Square Dot-1000 CPI Anilox	0.561	11
8	Uncoated Paper-Square Dot-1300 CPI Anilox	0.540	12
9	Uncoated Paper-Square Dot-700 CPI Anilox	0.536	10
10	Uncoated Paper-Round Dot-1300 CPI Anilox	0.535	6
11	Uncoated Paper-Round Dot-1000 CPI Anilox	0.529	5
12	Uncoated Paper-Round Dot-700 CPI Anilox	0.491	4

4. Discussions

The GRA index of print considering different input variables in terms of Optical Ink Density, Dot Gain, Hue Error and Print Contrast are given in Table 5-15.

It has been found from Table 5 that the Grey Relational Grade is higher on Coated paper than Uncoated paper and Grey Relational Grade is higher for lower anilox screen ruling in coated paper in case of Optical Ink Density. But in case of Uncoated paper, the result is just opposite. This may be due to poor bottoming of the image on the paper as the surface of the paper is uneven.

It has been observed vide Table 6-8 considering Dot Gains at 30%, 50% and 70% dot area that 1300 CPI anilox ruling frequency produces minimum Dot Gain in highlight, midtone and shadows on Coated paper for image made up of round shape AM dots.

The Dot Gains are different under different conditions due to screen frequency of anilox ruling, paper textures and dot pattern.

It is found from Table 9-11 that Hue Error is minimum on Uncoated paper in highlight for both 700 CPI and 1300 CPI anilox ruling frequency. Hue Error is minimum in midtone and shadow on Uncoated paper for 1000 CPI anilox ruling frequency. However, the Hue Errors on Coated paper in highlight, midtone and shadow are different so far as anilox ruling frequency is concerned. The dot shape also has an influence on the Hue Error. Square dot shape produces minimum Hue Error as compared to round dot shape.

Table 12-14 shows the GRA index of the print for Print Contrast. It is observed that 700 CPI anilox ruling frequency produces maximum Print Contrast in highlight, midtone and shadow on Coated paper. Lower anilox ruling frequency and round shape dot provide the best Print Contrast on Coated paper.

Table 15 shows the overall Grey Relational Grade and ranking of the print considering the input variable and output print parameters such as Optical Ink Density, Dot Gain, Hue Error and Print Contrast. It has been found that 700 CPI anilox ruling frequency will provide high print quality followed by 1300 CPI anilox ruling frequency. It is also found that images made up of round shape dot will be produced better on coated paper in flexography.

It has been observed from Figure 5 that Dot Gain of prints on Coated paper utilising 1300 CPI screen frequency and Round shape dot pattern of the image is minimum followed by Dot Gain of prints on Coated paper adopting 1300 CPI anilox screen ruling using Square shape dots of the

image. The Dot Gain is maximum on Uncoated paper utilising 1300 CPI anilox ruling of images containing Square dots.
It is observed from Figure 6 that Hue Errors are minimum for Uncoated paper as compared to Coated one irrespective of anilox screen ruling frequency and dot shapes.
It has been observed from Figure 7 that the Print Contrast is lower in Uncoated paper as compared to Coated paper. It is also observed that the Print Contrast value is increasing with increasing value of anilox ruling for Uncoated paper and Print Contrast is decreasing with increasing value of anilox ruling for Coated paper.

5. Conclusion

In the present work, the research was conducted on flexographic printing with three variable factors: Coated and Uncoated paper, Round and Square shaped halftone dots and three different anilox roller rulings. It has been found that optimum print quality is obtained when print is taken on Coated paper at 700 CPI anilox ruling if the image is made of Round dot considering dot gain as factor affecting print quality.
It is also found that if Hue Error is considered as print quality index, optimum result can be obtained on Uncoated paper using Square dot but it behaves differently in different percentage dot areas so far as Print Contrast is concerned, Coated paper with 700 CPI screen ruling will produce highest print quality. As a whole, 700 CPI screen ruling will produce highest print quality on Coated paper if the image is composed of Round dots. The print quality has been analysed on the basis of the assessment of print parameters: Optical Ink Density, Dot Gain, Hue Error and Print Contrast using Taguchi's Grey Relational Analysis. The results showed that the flexographic print quality is dependent on the factors such as surface characteristics of substrate, geometrical shape of the halftone dots used and the anilox cell rulings. Also, this study showed the scope of implementation of Taguchi's Grey Relational Analysis in the decision-making process associated with the print quality assessment in flexography.

6. References

[1]. Joshi, V.A. (2022). Optimization of flexo process parameters to reduce the overall manufacturing cost. An International Journal of Optimization and Control: Theories & Applications, 12(1), pp. 66–78. Available at: https://doi.org/10.11121/ijocta.2022.1137

[2]. ECTran71. Anilox roll cell structure. Available at: https://en.wikipedia.org/wiki/File:Anilox_cells.png

[3]. Karna, K.S., & Sahai, R. (2012). An overview on Taguchi Method. International Journal of Engineering and Mathematical Sciences, 1, pp. 11–18.

[4]. Patil, A.N., Walke, G.A., & Gawkhare, M. (2019). Grey Relation Analysis methodology and its application. Research Review International Journal of Multidisciplinary, 4(2). ISSN 2455-3085. Available at: www.rrjournals.com

[5]. Kumar, S., & Baral, A.K. (2023). Taguchi's Grey Relationship Analysis (GRA) for comparing the performance of various inkjet printheads for tone value increase on uncoated paper substrates. International Journal on Recent and Innovation Trends in Computing and Communication. Available at: http://www.ijritcc.org

[6]. Iwundu, M.P., & Cosmos, J. (2022). The efficiency of seven-variable box-behnken experimental design with varying centre runs on full and reduced model types. Journal of Mathematics and Statistics, 18, pp. 196–207. https://doi.org/10.3844/jmssp.2022.196.207

[7]. Dendge, R.R. (2023). Analysis of Dot Gain produced by interactions of flexographic plate and anilox roll screen frequencies. Acta Graphica, 31(1).

[8]. Gooran, S. (2005). Hybrid halftoning, a useful method for Flexography. Journal of Imaging Science and Technology, 49(1). Available at: https://library.imaging.org
[9]. Youssef, T.K. (2015). The impact of FM-AM hybrid screening and AM screening on flexographic printing quality. International Design Journal, 5(4), pp. 1471–1476.
[10]. Vandana., & Jangra, V. (2018). The evolution and revolution of screening technology: A review. Global Journal of Engineering Science and Researches, ISSN 2348–8034. Available at: https://doi.org/10.5281/zenodo.1343474
[11]. Hsieh, Y.C., Cheng, H.W., Cheng, Y.H., Chen, S.Y., & Ng, S.V. (2008). Flexible hybrid screening solutions for flexography. International Conference on Computer Science and Software Engineering. Available at: https://doi.org/10.1109/CSSE.2008.1390
[12]. Valdec, D., Hajdek, K., Vragovic, L., & Gecek, R. (2021). Determining the print quality due to deformation of the halftone dots in flexography. Applied Sciences, 11, 10601. Available at: https://doi.org/10.3390/app112210601
[13]. Tomasegovic, T., Pibernik, J., Poljacek, M.S., & Madzar, A. (2021). Optimization of flexographic print properties on ecologically favourable paper substrates. Journal of Graphic Engineering and Design, 12(1), pp. 37–44. Available at: https://doi.org/10.24867/JGED-2021-1-037
[14]. Dharavath, N.H., Bensen, M.T., & Gaddam, B. (2005). Analysis of print attributes of Amplitude Modulated (AM) vs. Frequency Modulated (FM) screening of multicolor offset printing. Journal of Industrial Technology, 21(3). Available at: www.nait.org
[15]. Lychock, G. Explanation of Hue Error and Grayness, X-rite: Ga00034a_HueError _Grayness_ EN, X-Rite. Available at: www.xrite.com
[16]. Valdec, D., Miljkovic, P., & Augustin, B. (2017). The influence of printing substrate properties on colour characterization in flexography according to the ISO Specifications. Tehnicki Glasnik, 11(1). ISSN 1846–6168 (Print), ISSN 1848–5588 (Online)