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Optimisation of Process Parameters in Flocked Fabric Production to Eliminate the Non-Recovery Problem of Bent Fibres in Flock

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Abstract

This study was focused on the elimination of defects due to the non-recovery of bent fibres in flock. For this reason, it was aimed to shorten the recovery time of bent fibres in flock as much as possible by optimising selected process parameters in flocked fabric production. For this aim; the diameter of flock fibre, the flock type, paste type, foam density, presetting, dyeing machine type, finishing treatment type, amount of treatment (finishing chemical), use of the brake mechanism during packing the fabric, and tension during winding were changed in two levels and their effects were investigated statistically. As a result of pareto analysis and statistical evaluations, among the many parameters that may affect this problem, the type of finishing process and presetting were found to have a critical effect. According to the experimental results, it was concluded that the recovery time of bent fibres in flocked fabrics could be significantly shortened if the flocked fabrics are not preset and silicone softener is applied during finishing treatments.

Key words: *Flocked fabric, non-recovery of bent fibres, silicone, presetting, Pareto analysis.*

Introduction

Flocked fabrics are textile-based products used in outerwear and home textiles composed of substrate, adhesive and flock fibre [1]. In general, flocked products have a velvet-like or suede-like feel and appearance, and in particular they generally have the characteristic sheen of many suedes and velvets [2]. Post finishing operations such as embossing, rotary screen printing, transfer printing, and laminating can be used with flocked products to produce exquisite special effects [3].

The flocking technique consists in applying to an adhesive support fibres of varying lengths made of a material such as wool, cotton or synthetic fibres, called flock [4]. It has been reported that the harsh handle polyamide based flock fibres are more favorable due to their good colour fastness, brightness and abrasion resistance than the soft handle viscose based flock fibres, which have poor colour fastness and abrasion resistance [5]. In general, the length of flock fibre varies between 0.5-2 mm. Its fineness can be 14 microns minimum [1]. The support coated with flock fibres has a velvety appearance resulting from the general orientation of the fibres being perpendicular to the surface of the support [4]. The quality of flock is strongly influenced by the flock density on finished flock surface [6]. The basic distinction between the properties of flocked materials and those of materials with a pile of different appearance produced by mechanical technology methods lies in the oriented arrangement of fibres. Thus, the properties of pile coating (main quality indicator for similar materials) are determined by the orientation degree and suitable density of the fibre arrangement [7]. The packing density would be expected to increase if the velocity of the impinging fibres were increased, their orientation perpendicular to the substrate surface improved, and if the stream of impinging fibres moving between the electrodes were more densely packed. An increase in fibre falling velocity should -also permit a larger number of fibres to be fed in the screen per unit time. By introducing these changes, one would expect more fibres to reach the surface in the first strike, and there is a greater probability that a fibre impinging on the adhesive-coated surface will stick and remain vertical [8]. In practice, whilst the theory is relatively simple, correct implementation and end product production is much more complicated; it requires a very high level of technical understanding of the flock process as well as very rigid control of the processing conditions and the finished flock performance specification. Although there are still many aspects of flocking that are not fully understood today, there are still further technological developments taking place that are increasing the market for and the quality of flocked products [9].

Flock fibres are usually applied to adhesive coated surfaces mechanically, electrostatically, or by a combination of both techniques. Mechanical flocking can be further divided into windblown and beater-bar methods. Electrostatic flocking sometimes incorporates a pneumatic process to propel fibres toward a surface in an air-stream [10]. It is conventional to manufacture flocked fibres by using an electrostatic flocking chamber into which individual flock-cut fibres are fed. These fibres, electrostatically energised, are extremely straight and impinge substantially vertically upon the surface of the substrate, and are held in this position by an adhesive previously applied to the surface [11]. Fibres are driven under the influence of Coulomb's forces. The nature of the covering depends on the fibre length, fibre fineness, and the density of packing. The physical and mechanical performance of such flocked materials is critically dependent on the adhesion of the fibre to the substrate, as well as on the fibre toughness and flock density [12]. The resulting products, after drying the adhesive, have found considerable utility for a variety of end uses, such as for fabrics, wallpapers, outerwear, etc. [11].

Some techniques have been devised to change the texture or feel of flocked fabric. The length of flock fibres can be changed to produce a different grade or feel of imitation fur obtained. The longer the flock, the smoother it feels. Embossing techniques to change the feel of a flocked surface have been employed for some types of flocked foam fabrics (not those with polyurethane foam), which are generally used for wallpaper rather than for apparel items [13].

Coldwell and Hersh investigated the effect of 16 variables of the dc electrostatic flocking process with a two-level factorial screening experiment. Properties examined include the mass and number of fibres sifted fibre and flocked, the percentage of available fibres flocked, the theoretical maximum packing density percent, and the abrasion resistance of the flocked fabric. The 16 independent variables included six machine variables (voltage, electrode separation, sifter speed and screen mesh, flocking time, and substrate vibration), three flock variables (fibre type, length, and denier), five adhesive variables (adhesive type, concentration, viscosity, thickness, and drying conditions), ambient humidity, and the substrate (polyethylene film and aluminium foil). Only the three flock variables and voltage were found to influence the properties of the flocked fabric. The quantity of fibre sifted was affected by the fibre denier and length and by the sifter speed, but the sifter speed did not influence the flocked fabric. The packing density of the flock on the fabrics ranged from 0.4 percent of the theoretical maximum (for low denier, long length nylon fibre flocked in a low electric field) to 13 percent (for high denier, short length nylon flocked in a high electric field). Of all the variables studied, fibre length had the greatest effect on the flocking properties; increasing the fibre length decreased the number of fibres sifted, the number of fibres flocked, and the maximum flock density percent. When comparing rayon and nylon, the abrasion resistance of fabrics flocked with nylon was much greater than that of fabrics flocked with rayon. Except for a minor effect related to the length of the nylon flock, none of the other 15 variables examined influenced the abrasion resistance [14].

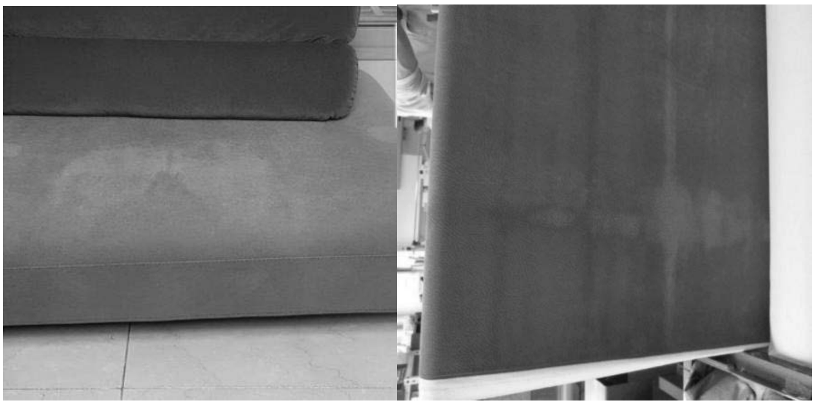

Figure 1. Photos, which were taken at the Süedser Inc. Company, of fabrics with the problem of the non-recovery of bent fibres in flock.

Liu et al. used a superfine polyamide fibre for piles to produce flocked fabric, and employed a full factorial design with three design factors at three levels to optimise the process parameters in terms of flocking density. The flock density is found, experimentally, to increase with a decrease in the flocking distance and increase in the field strength and flocking time. The optimum parameters are empirically and experimentally determined as follows: flocking distance – 7 cm, field strength – 60 kV, and flocking time – 10 s [15].

Bilişik, Turhan and Demiryürek studied the tensile properties of flocked fabric after rubbing. A rubbing test was applied in dry and wet forms to the flocked fabrics before and after washing. The tensile properties of those rubbed flocked fabrics were determined. The warp tensile strength of the flocked fabric was generally higher than its weft tensile strength due to its higher substrate density in the warp direction. In addition, the weft tensile elongation of the flocked fabric was generally higher than its warp tensile elongation due to its higher crimp ratio in the weft direction. When the stroke number increased, the warp and weft directional tensile strength and elongation of the flocked fabric generally decreased. In addition, the stroke number of the flocked fabric before and after washing was low in its wet form compared to the dry form [16].

Flock fabric in daily use has some problems. There is a tendency of the delaminating of the flock fibre layer from the substrate under the rubbing and abrasion movements in cleaning and general use [17]. Another most commonly faced problem is the non-recovery of bent fibres in flock, and flocked fabric producers are subjected to serious complaints due to this problem. Furthermore, this issue also causes prejudice in users against flocked fabrics and may result in flocked fabrics not being preferred both at home and for external use. Photos of fabrics with this problem are given in ***Figure 1***.

Although there are many studies on the flock density and abrasion resistance of flocked fabrics in literature, from the best of the authors' knowledge, there is no study on solving the non-recovery problem of bent fibres in flock. Therefore, with the aim of filling this research gap in literature, we focused on the elimination of defects (some marks on the fabric surface, as shown in ***Figure 1***) due to

Table 1. Physical-mechanical characteristics of flock fibres used in experiments.

Fibre type	Fibre diameter, dtex	Fibre length, mm	Fibre tenacity, cN/tex	Elongation, %
PA 6,6	1.5	1	46.44	72.92
PA 6,6	1.9	1.1	43.20	88.94

the non-recovery of bent fibres in flock. For this reason, it was aimed to shorten the recovery time of bent fibres in flock as much as possible by optimising some process parameters in flocked fabric production. For this aim, the diameter of flock fibre, theflock type, paste type, foam density, presetting, dyeing machine type, finishing treatment type, amount of treatment (finishing chemical), use of the brake mechanism during packing the fabric, and tension during winding were changed in two levels, and their effects were investigated statistically. According to the experimental results, it was found that the recovery time of the bent fibres in flocked fabrics could be significantly shortened if flocked fabrics are not pre-set and silicone softener is applied during finishing treatments.

Material and method

In the production of flocked upholstery fabrics, after applying acrylic adhesive on PES substrate fabric, PA 6,6 fibres were flocked to the paste. Then the flocking parts of the fabrics were dyed with levelling acid dyes in airjet or waterjet dyeing machines. After dyeing, easy-clean finishing chemical containing silicone softener (ES: Easy-clean/silicone) or silicone softener (S) alone was applied to open-width fabrics in foulard. All experiments were carried out directly in sample scale production at the Süedser Inc. Company (Turkey). Each step of the production is explained below.

Production of substrate fabric: 100% polyester woven fabric (warp density: 13 thread/cm; weft density: 11 thread/cm) was produced using Ne 14/1 open-end yarns in both the warp and weft directions on an eccentric weaving machine (Tsudakoma) machine.

Coating the substrate fabric with acrylic adhesive: PES substrate fabric was coated with 50 g/m^2 acrylic adhesive and then passed through a stenter at 200 °C at a speed of 12 m/min. The aim of this step was to close the fabric pores in order to obtain a smooth surface, which is necessary for the next step.

Flock preparation: In this stage, the flocks were cut into the desired length and then loaded with electrical charge. For this aim, the flocks were treated in a boiler for 10 minutes at 60 °C in a liquor whose pH was adjusted to 5.5. The liquor-to-good ratio was 1:26. Then 1.8% aluminum sulfate and, after 10 min., 0.9% tannic acid were added. After 10 minutes of treatment, 1.5% aluminum sulfate was added and the process continued for another 10 minutes. The pH was reduced to 5.5 with the addition of soda ash, and then 0.5% BD Special Soft SA New (Barcelonesa), 1% Novasoft CWR (ProChemica) and 16% ammonium sulfate were added into the bath and the flocks were treated at 60 °C for 1 hour. The flocks were then centrifuged and dried.

Sued process: The fabric was first coated with two different kinds (hard or soft) of pastes. The hard paste contained the following: 4% cross-linker, 2% foam stabilising agent, 3.3% thickener, 0.8% ammonia, 0.2% antifoaming agent and 89.7% acrylic paste (50% HAS 4S / 50% ORGAL MA 780 (Organik Kimya Inc.)), while the soft paste was composed as follows: 2% foam stabilising agent, 2% thickener, 0.53% ammonia, 0.2% antifoaming agent and 95.27% acrylic paste (70% HAS 4S / 30% ORGAL MA 780. After coating, in the second step the fabric was passed through a zone in which it was flocked by the electrostatic method. Voltage quantities was as follows: chamber 1 – 16.000 volts, chamber 2 – 20.000 volts, chamber 3 – 60.000 volts, chamber 4-80.000 volts, and chamber 5-100.000 volts. The machine speed was 15 m/min and the flock density 80 g/m^2. After flocking, the fabric was passed through a stenter (Dilmenler Machinery) at temperatures rising gradually from 90 °C to 145 °C.

Pretreatment: Prior to wet treatments, the flocked fabric was subjected to pre-fixation at 190 °C for 2 min. in a stenter (Dilmenler Machinery). Then the fabric was bleached in a liquor containing 0.5 g/l of caustic soda and 5 g/l of hydrogen peroxide. The process was started at 40 °C, then the temperature was raised to 50 °C, and the process was continued for a further 20 minutes. Finally, the liquor was cooled and drained. Afterwards, the fabric was neutralised with acetic acid at 40 °C for 20 minutes.

Dyeing: Dyeing of the flocked fabric was started at 40 °C and 5.5 g/l of an anti-foaming agent, 1 g/l of a sequestering agent, 0,5 g/l of acetic acid, 1 g/l of sodium acetate and 6% of a levelling agent were added, respectively. Then yellow (0.51%), red (0.2%) and blue (0.14%) levelling acid dyes were added and the temperature raised to 70 °C and then 100 °C at a heating rate of 0.8 °C/min. and 1 °C/min., respectively. Dyeing was carried out at 90 °C for 30 minutes, and then the dye-bath was cooled and drained.

Finishing: Open-width fabrics were padded in foulard with 50 or 150 g/l of easy-clean finishing chemical containing silicone softener (ES: Easy-clean/silicone)) or silicone softener (S).

In order to eliminate the non-recovery problem of bent fibres in flock, the first parameter investigated was the diameter of fibres used in the flock. Because it was expected that the recovery property of fibres in the flock would be related to the fibre bending stiffness, which may affect the recovery of bent fibres, sample scale production was carried out using fibres having two different diameters. However, as fibre diameter is a critical factor affecting many other properties (e.g. fabric handle) of the finished product, it could not be changed in a wide range. Only two different diameters already acceptable for production were compared statistically. During these experiments, other parameters that could potentially affect the recovery of bent fibres in flock were kept constant (paste type: soft, foam density: 750 g/l, flock type: original ((first use)), presetting: yes, dyeing machine type: waterjet, treatment type: silicone (S), amount of treatment: 200 g/l, brake mechanism during packing: yes, tension during winding: 1.37). Physical-mechanical characteristics of the flock fibres used in the experiments are given in ***Table 1***.

Other factors that may affect the recovery time of bent fibres in flock are determined as follows;

- Paste type: hard or soft
- Foam density, g/l: 750 or 850
- Flock type: original (first use) or recycled (reuse)

– Presetting: yes or no
– Dyeing machine type: airjet or waterjet
– Treatment type: silicone (S) or easy-clean finishing chemical containing silicone (ES)
– Amount of treatment (finishing chemical), g/l: 50 or 150
– Brake mechanism during packing: yes or no
– Tension during winding of fabric: 1.37 or 1.42

In order to determine the effect of these factors on the recovery time of bent fibres in flock, during sample scale production each factor was changed in two levels and Pareto analysis carried out. Then the fabrics produced were tested in terms of the recovery of bent fibres in the flock. As it was determined that the fibre diameter did not affect the recovery time of bent fibres in flock, 1.5 dtex PA 6,6 fibres were used in all these experiments. It is important to note that although some process parameters like flocking density and flock length may potentially affect the non-recovery problem of bent fibres in the flock, the factors that could also possibly change the other properties (like handle) and appearance of the flocked fabric were avoided, because the aim of this study was not to produce a flocked fabric which does not have the non-recovery problem of bent fibres in the flock, but to eliminate the non-recovery problem of bent fibres in flock in a certain type of flocked fabric.

Due to the fact that there is no test standard that can be applied in laboratory conditions to determine the problem of laying flock, a method to simulate sit and get up was developed and was used for determining the problem of laying flock. A force was applied with a weight (cylindrical iron block) to the fabric samples produced according to the experimental design mentioned above for 40 minutes, and then the recovery time of bent fibres in the flock was measured.

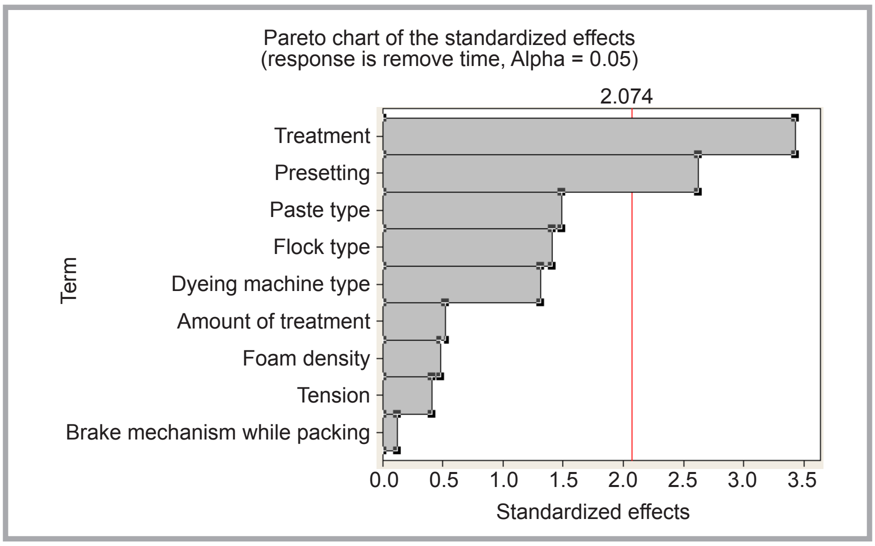

Figure 2. Pareto diagram of factors that may affect the problem of laying in flocked fabrics.

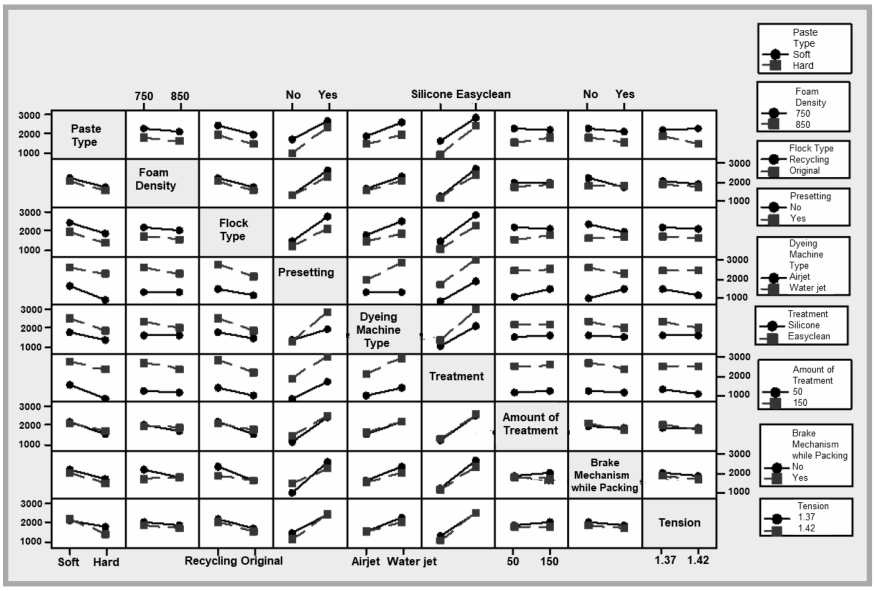

Figure 3. Interactions of factors affecting the non-recovery problem of bent fibres in flock.

Results and discussion

In order to eliminate the non-recovery problem of bent fibres in flock, the first parameter investigated was the diameter of fibres used in flock. For this reason, sample scale production was carried out using fibres having two different diameters: 1.5 dtex and 1.9 dtex. All other processing parameters were kept constant during these experiments. According to the analysis of variance results, it was found that fibre diameter does not have a statistically significant effect ($p > 0.05$) on the recovery of bent fibres in flock. Normally, a correlation is expected to be found between the fibre diameter and recovery of bent fibres because with a decrease in fibre diameter, the moment of inertia, which changes in direct proportion to the fibre diameter, decreases and the bending stiffness increases accordingly. Consequently, the bending stiffness of the finer fibres are lower compared to the coarser ones [18]. The reason for the effect of fibre diameter being insignificant was the fact that the change therein fibre was not huge. As the diameter of fibres used in flock is a critical factor affecting many other properties (e.g. fabric handle) of the finished product, it could not be changed in a wide range; and also for the reason that the aim of this study was to eliminate the non-recovery problem of bent fibres in flock in a certain type of flocked fabric.

Other factors that may affect the non-recovery problem of bent fibres in flock: flock type, paste type, foam density, presetting, dyeing machine type, finishing treatment type, amount of treatment (finishing chemical), use of the brake mechanism during packing the fabric, and tension during winding, and their effects were investigated via statistical analysis by changing each of the parameters in two levels. The findings obtained as a result of Pareto analysis are shown in ***Figure 2***.

Table 2. *Variance analysis results regarding the recovery time of bent fibres in flock.*

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main effects	9	29789198	29789198	3309911	3.23	0.012
Paste type	1	2258875	2258875	2258875	2.21	0.152
Foam density	1	238050	238050	238050	0.23	0.634
Flock type	1	2022060	2022060	2022060	1.98	0.174
Presetting	1	11007432	7034787	7034787	6.88	0.016
Dyeing machine type	1	1659457	1768609	1768609	1.73	0.202
Treatment type	1	12147352	12043308	12043308	11.27	0.002
Amount of treatment	1	268186	272234	272234	0.27	0.611
Brake mechanism during packing	1	15501	15501	15501	0.02	0.903
Tension	1	172285	172285	172285	0.17	0.686
Residual error	22	22511030	22511030	1023229		
Total	31	52300228				

When ***Figure 2*** is examined, it is understood that among the many parameters that may affect the recovery of bent fibres in flock, the type of finishing process (silicon or silicon containing easy-clean finishing chemical) and presetting (applied or not) are found to have a critical effect. On the other hand, it can be said that finishing chemical concentration, foam density, fabric winding tension, brake device usage during fabric winding, paste type, flock type and dyeing machine type do not cause a significant change. In ***Figure 3***, the interactions of factors that affect the recovery of bent fibres in flock can be seen together.

When the red and black lines representing the two levels for each factor given in ***Figure 3*** are compared, it can be understood that;

- there is no difference between the varying levels of factors, such as foam density, finishing chemical concentration, fabric winding tension and brake device usage in fabric winding,
- there is a difference (even if it is not very significant) between the varying levels of the paste type, flock type and dyeing device type,
- there is a significant difference between the varying levels of the type of finishing process and the presetting factors.

When ***Figure 3*** is examined, it is seen that the recovery time for bent fibres in flock is lower when hard paste is used. When hard paste is used, fibres stuck in the paste during flocking become more stable, which prevents fibres from being broken when a force is applied. If the effect of flock type is analysed, it can be understood that using original fibre (first use) is more advantageous compared to recycled fibres. The reason is that recycled fibres are already damaged to some extent, and this makes them to get bent or broken much more easily. Furthermore, it was observed that fabrics dyed in an airjet machine tend to have shorter recovery times of bent fibres in the flock. The most significant changes were obtained in the finishing treatment type and presetting. From the results, it is clear that the application of a chemical containing silicone softener only gives a shorter recovery time of bent fibres in flock. This is because silicone softener makes the fabric more elastic, and hence the recovery of bent fibres in the flock can occur much more easily. However, as the usage amounts of silicone softener (S) and easy-clean finishing chemical containing silicone (ES) were kept constant (50 or 150 g/l), the silicone amount on the fabrics treated with ES was lower. This explains why better results were obtained in the case of using a finishing chemical containing silicone softener alone. On the other hand, it can be said that fabrics that had not been subjected to presetting gave better results in terms of the recovery of bent fibres in the flock.

In ***Table 2***, variance analysis results regarding the recovery time of bent fibres in flock are given.

When the variance analysis results of the recovery time of bent fibres in flock given in ***Table 2*** are examined, it is seen that only the type of finishing treatment and presetting application were statistically significant ($p < 0.05$), while other factors did not lead to a statistically significant change.

Conclusions

Within the scope of this study, focused on was the elimination of marks on the fabric surface due to the non-recovery of bent fibres in flock by optimising selected process parameters in flocked fabric production. For this aim, the diameter of flock fibre, flock type, paste type, foam density, presetting, dyeing machine type, finishing treatment type, amount of treatment (finishing chemical), use of the brake mechanism during packing the fabric, and tension during winding were changed in two levels, and their effects were investigated statistically. As a result of Pareto analysis and statistical evaluations, among the many parameters that may affect this problem, the type of finishing process (with silicon softener or silicon containing an easy-clean finishing chemical) and presetting (applied or not) were found to have a critical effect. However, it was determined that finishing chemical concentration, foam density, fabric winding tension, use of the brake mechanism during fabric winding, paste type, flock type and dyeing machine type did not cause a significant change. It can be concluded that the recovery time of bent fibres in flocked fabrics can be significantly shortened if flocked fabrics are not preset and silicone softener is applied during finishing treatments. The average decrease in the recovery time was 39.17% and 52.66% for samples that had not been preset or treated with silicone softener, respectively. Recommendations for other parameters during flocked fabric production are as follows; paste type – hard, foam density – 850 g/l, flock type – original (first use), dyeing device – airjet, finishing chemical concentration – 50 g/l, brake device usage during fabric winding – yes, and fabric winding tension – 1.42. If each parameter during the production of flocked fabrics are set as recommended, the recovery time will decrease from approximately 3500 minutes to nearly 200 minutes. In future studies presetting and the type of chemical finishing treatments could be investigated in more detail. Furthermore, other parameters such as machine variables (voltage, sifter speed, screen mesh, flocking time, substrate vibration etc.) and adhesive variables (adhesive type, concentration, viscosity, thickness, and drying conditions) could be examined in order to achieve further improvements in the recovery time of bent fibres in flock.

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