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Pigment and disperse printing of needle-punched polyethylene terephthalate nonwovens

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Abstract

Needle-punched polyethylene terephthalate (PET) nonwovens of three mass densities viz., 80 g/m^2, 140 g/m^2 and 200 g/m^2 were printed with a range of disperse dyes and pigments on an automatic flatbed screen printing machine. The disperse-printed nonwovens were thermo-fixed at various temperatures and time intervals. The printed nonwovens were reduction-cleared with sodium dithionite and sodium hydroxide each through an exhaust technique. The nonwovens were also printed with pigments in the presence of a range of binders having different chemistries for various curing time intervals. The control and printed nonwovens were tested for colorimetric, print and crock fastness properties. The mechanical properties such as tensile strength, tear strength and bending length were measured to account for any structural changes.

Keywords: Needlepunching, nonwovens, screen printing, disperse dyes, pigments, colour

Introduction

Nonwovens are engineered fibrous assemblies, prepared directly from fibres or filaments. The process involves production of a fibrous web, followed by bonding of the web by chemical, thermal or mechanical means. In the production of staple fibre nonwovens for durable applications, needle-punching and hydro-entanglement techniques are commonly employed. In needle-punching, a web of fibres is punched with a set of barbed needles at predetermined frequency. The fibres are entangled during needle punching by frictional constraints thereby giving the necessary form, look and integrity to the nonwovens [1].

Colouration of nonwovens can be categorized in to pre- and post-bonding methods. Pre-bonding methods include mass pigmentation during extrusion, dyeing of fibres, one step-colouration and wet-laying whereas post-bonding methods include dyeing with dyestuff employing exhaust or continuous methods; application of pigments by printing methods and addition of colorants during chemical bonding [2]. The coloration of nonwovens finds application, but not limited to, in floor coverings, wallpapers, carpets, furnishings, table and bed linen, shoe linings, as well as single- or limited-use protective clothing; garment interlinings are also often coloured. Burkinshaw et. al.[3] reported the dyeing of cotton and polyester hydro-entangled nonwovens resulted in better colour strength in comparison to woven and knitted textile fabrics, owing to higher porosity of the former [3]. Meyer et al. studied the effect of conventional and dope-dyeing of polyamide-6 fabrics and electrospun nonwoven webs, respectively, for potential applications as pH sensitive sensor materials. The work highlighted the importance of halogen substituents for conventional dyeing of pH sensitive fabrics. The dope-dyed webs showed significant leaching due to acidic spinning dope and the leaching effect was decreased by the use of a complexing agent. [4] Canbolat et al. reported the increase in colour strength, during dyeing, of oxygen plasma treated PET/viscose blended fabrics compared to that of untreated fabrics. [5] A study on past consumption by woven, knitted and nonwoven fabrics reported higher consumption of nonwoven fabrics owing to its open structure resulting in higher absorbency [6]. The mechanical properties of nonwoven fabrics can be enhanced or engineered by printing specific patterns on the fabric surface [7].

Screen printing of nonwovens has been employed to print active electrodes for integrated clothing which could have applications for wearable health monitoring [8] and to print conductive inks for wide-band applications such as digital signalling [9]. In another study, the surface tension of ink and contact angle of conductive ink with the surface of nonwoven fabrics and fabric pore dimensions were found important parameters for inkjet printing. The structural characteristics of nonwovens were found to affect the in-plane and thorough-plane spread of the ink [10]. Marks et al. studied the effect of fibre orientation and needle-punching density on image quality of inkjet-printed nonwoven fabrics [11]. The surface characteristics of studied fabrics contributed to poor image quality while the fibre orientation did not affect the print quality. Hussain et al. employed Box–Behnken experimental design to study the effect of binder concentration, curing temperature and time on different properties, including crocking fastness, of printed spunbond polypropylene nonwovens. The wet crocking fastness of printed nonwovens was found poor compared to acceptable dry crocking fastness.[12]

Owing to low modulus of nonwoven fibrous assemblies, nonwovens would be very easily distorted if processed in hot and turbulent aqueous environment particularly for long times. The printing of nonwoven fabrics could be beneficial as the dyeing route could adversely affect the structure and subsequently properties of nonwoven fabrics. A single stage bonding and printing of nonwovens could be achieved by employing chemical bonding of webs but such fabrics would be structurally different from mechanically bonded fibrous assemblies [13]. The out-of-plane fibre segment orientations is a characteristic feature of mechanically-bonded nonwoven fabrics [14].

Polyester staple fibre (PSF) is most commonly employed staple fibre in the production of nonwovens. Nonwovens are technical fabrics with aesthetics not a primary feature and need of colouration is specific to application area. There is a paucity of published work on the colouration, both printing and dyeing, of nonwoven fabrics and the current study aims to screen print PSF needlepunched nonwovens with pigments and disperse dyes. The study will be a pioneering work, to authors' knowledge, to print nonwovens with traditional textile printing route and determine the effect of these processes on the colour and particularly mechanical properties and performance parameters of the needlepunched nonwovens.

Experimental

Materials and Machinery

Needle-punched polyethylene terephthalate (PET) nonwovens prepared from recycled PET fibres of 3.22 denier in three nominal mass areal densities viz., 80, 140 and 200 g m^{-2} were provided by Alyaf Industrial Co. Limited., Dammam, Saudi Arabia. The nonwovens were heat set at 220^{o}C for 1 minute. The printing of nonwovens was carried out on a laboratory-scale flat screen printing machine (SP-300AR, Tsuji Dyeing Machine Mfg. Co. Ltd. Japan). A list of colorants used during printing is presented in Table 1. Various printing auxiliaries and their chemistries are presented in Table 2. All other chemicals were of laboratory grade.

Screen Printing

Pigment printing: Stock thickening of Lutexal HIT Plus (3.5% w/w) was prepared by dissolving half of the thickener quantity in water and stirred (HV-SL Tokushu Kika Kogyo, Japan) for 5 min. followed by adding remaining half of the thickener, water and ammonia (10 g/kg, pH 8.5) and stirred for another 10 minutes. To obtain consistent viscosity, the thickener paste was left for 3 hrs before use. The viscosity of thickener as measured using viscometer (BH, Tokimec Japan) with spindle no. 6 was 22000 cps. The amounts of pigments, binders, fixer and softeners were varied to investigate their effect on the colorimetric, fastness and mechanical properties of nonwovens. The printed nonwovens were dried at 110°C followed by curing at 160°C for various time intervals.

Disperse printing: Stock thickening of Lyoprint RD-HT (4 % w/w) was prepared by dissolving thickener paste in water and stirring for 30 min at high speed. The printing pastes contained disperse dye x g/kg, acetic acid 1 g/kg; the balance amount being stock thickener. The viscosity of thickener as measured with spindle no. 6 was 12500 cps. The nonwovens were printed on flat screen printing machine at the following settings, stroke: double, speed: 0.5 m/min, pressure: 2/5 units. The nonwovens were dried at 110°C on pilot scale pin tenter frame (OPT-1, Tsuji Dyeing Machine Japan) followed by thermofixation at 200°C on the same machine. The printing followed a hot (80°C) rinsing and then reduction clearing at 70°C for 30 min. in a bath containing 2 g/L each of sodium hydrosulphite and sodium hydroxide. The reduction clearing followed hot washing in the presence of 2 g/L Lissapol ND and three cold rinsings each of 5 min..

Measurements

Colorimetric properties: The colorimetric properties of dyed and printed nonwovens were measured on reflectance spectrophotometer (Color-Eye, GretagMacbeth USA). The spectrophotometer was calibrated and the measurements were taken at the following settings: illuminant D65, specular excluded, uv excluded, geometry d/8°, standard observer 10°, aperture medium and wavelength range 400-700 nm. Each of the samples was measured at five different places and the average value calculated. The CIE XYZ values recorded by the spectrophotometer were converted into CIE colour coordinates $L^*a^*b^*$ using software (Color iMatch, Version 5.30). The reflectance spectra were recorded in the range of 400 – 700 nm at 10 nm intervals. The colour strength (K/S) of dyed and printed nonwovens were measured by single-wavelength method using the following equation (1), where K_λ and S_λ were coefficients of absorption and scattering of the colourants at λ_{max}, respectively and R_λ was reflectance of the specimen at $\lambda_{max.}$

Colour strength $\left(\frac{K}{S}\right)_\lambda = \frac{(1- R_\lambda)^2}{2R_\lambda}$ (1)

Print characteristics: The paste back staining was measured using equation (2). The paste add-on was measured using equation (3), where M_1 and M_2 were mass of unprinted and printed nonwovens of the same areas. The print solidity was measured by taking measurements of colour strength over the printed area and reporting the results as K/S ± standard deviations.

Back staining (%) = $\left(\frac{\left(\frac{K}{S}\right)_{front} - \left(\frac{K}{S}\right)_{back}}{\left(\frac{K}{S}\right)_{front}}\right) * 100$ (2)

Paste add-on (%) = $\left(\frac{M_2 - M_1}{M_1}\right) * 100$ (3)

Fastness properties: Dry and wet crock fastness were measured in accordance with AATCC standard test method on digital crockmeter (AutoCrock, Advance Logic Systems Pakistan). Washing, rubbing and light fastness of disperse dyes were measured in accordance with ISO standards: 105-X12-2001, 105-03-2001 and 105-B02-1994 respectively while sublimation fastness was measured in accordance with a lab-developed method.

Tensile properties: Tensile properties of the nonwovens were measured in the machine direction (MD) on tensile strength tester (LRX+, Lloyd UK). Five tests were performed on each of the samples in accordance with ISO 13934-1 (traverse speed 100 mm min^{-1}, gauge length 100 mm, sample width 25 mm). Tensile strength and elongation were calculated from stress-strain curves. Due to sample size limitation, samples were processed in MD only. In a nonwoven fabric, fibre orientation distribution plays a key role in dictating the mechanical properties of the fabric in any direction. The fabrics in current study were cross-laid hence they are known to exhibit higher strength in cross direction compared to that of machine direction. [15]

Tear strength: Tear strength of the nonwovens was measured in the MD using digital Elmendorf tear strength tester (M008HE, SDL Atlas UK). Five tests were performed on each of the samples (100mm width x 63mm length”).

Bending rigidity: Stiffness was measured in terms of bending length on stiffness tester (Shirley, UK). Five tests were performed on each of the samples (100 mm x 25mm). The bending length was calculated using the following formula.

$$\text{Bending Length} = \mathrm{L}\sqrt[3]{\left(\frac{\cos\frac{\theta}{2}}{8\tan\theta}\right)}$$

where L is length of the fabric and θ is the angle which the nonwoven is bent to.

Thickness: The thicknesses of nonwovens were measured using digital thickness gauge (BG1110-1-04, AMES USA) at twenty different places in the machine and cross directions.

Results and Discussion

Pigment Printing

The PET nonwovens were printed with Helizarin pigments Crimson ECO and Blue FF-N each at 5, 10, 50, 100 and 150 g kg^{-1}, Binder TOW 200 g kg^{-1} and Ammonia liquor 10 g kg^{-1}, the balance amount being Thickener HIT Plus (stock paste: 3.5% w/w, viscosity: 22000 cps with spindle no. 6). The nonwovens were dried at 110°C for 1 min. followed by curing at 160°C for 3 min. The print and fastness properties were presented in Table 3.

Table 3 – Colorimetric and fastness properties of pigments

The colorimetric properties of pigments were discussed very briefly below. The pigments exhibited good build-up behaviour. The lightness (L^*) exhibited inverse relationship with pigment amount. The L^* decreased with increase in pigment amount due to increasing scattering and absorption of incident light. The Helizarin crimson became greener-yellower and Helizarin blue became greener-bluer as the shade depth increased. The industrial pigments don’t have very sharp cut-off absorptions in the absorption spectra resulting in variations in tones and chroma of the pigments with increase in concentration.

The results of print properties such as print penetration, paste add-on and crock fastness were measured and discussed below. As the amount of pigment increased, there was a slight increase in penetration depth. Since organic pigments are insoluble in aqueous medium, the industrial formulations contain dispersing agents that ensure dispersion stability. The synthetic thickeners are usually based on acrylic acid chemistry. In the presence of base, the carboxylic acid groups are dissociated thereby providing required viscosity. Since carboxylic acid groups (-COOH) are weak acidic groups, it is logical that in the presence of strong electrolytes there dissociation will further be suppressed. Since dispersing agents are usually based on condensation products of sulphonated anthraquinones and formaldehyde, the dissociation of $–COO^-$ groups is suppressed resulting in viscosity drop [13]. The higher the pigment concentration, higher would be the decrease in viscosity. Hence the print penetration increased with viscosity drop. The decrease in add-on as the mass density of nonwovens increased due to the fact that although the amount of pigment was the same, the mass density of nonwovens increased. All things being the same, back staining is inversely related to the fabric thickness. Therefore nonwovens with high areal mass density showed less back staining. The crock fastness decreased as the pigment amount increased. There exist a relationship between the amounts of pigments and binders. Usually, the amount of the binder is twice to thrice the amount of pigments. The results showed that up to 50 g kg^{-1}, the crock fastness was acceptable. At higher concentrations either binder had to be increased, or fixers could be incorporated into the print paste formulation. Other factors that may affect the crock fastness include curing temperature and time, humidity, print paste pH, softeners, humectants. To investigate the effect of binders, 80 g m^{-2} samples were printed with Helizarin Blue FFN 50 g kg^{-1} in the presence of five binders each at three levels. The pastes containing 300 and 400 g kg^{-1} binders were back-thickened since there was an appreciable drop in viscosity. The nonwovens were dried at 110°C for 1 min followed by curing at 160°C for 3 min. The effect of binders was studied in terms of crock fastness and mechanical properties. The results were presented in Table 4.

Table 4 – Effect of binders on crock fastness and mechanical properties

The textile binders are pre-polymers prepared by the free-radical co-polymerization of selected monomers, the latter being emulsified in aqueous medium. The monomers may include, but not limited to, acrylic acid, styrene, butyl acrylate, acrylonitrile and N-methylol acrylamide. The N-methylol acrylamide affords reactive side groups that may condense under suitable process conditions. Under dry-heat and acidic conditions, inter and intra-condensation of methylol groups ($-CH_2OH$) might take place to form continuous binder films covering the printed areas on the substrate. The methylol groups may also form covalent bonds with suitable nucleophilic sites such as hydroxyl and amine groups in the substrate, the anchoring of binder film ensuring better wet fastness properties. A schematic chemical reaction of binders is shown below, scheme1.

Scheme 1 – Chemical constitution and schematic crosslinking of textile binders

Due to film forming properties, it was rational that binders would increase the tensile strength while the tear strength might be decreased. The results showed that tensile strength increased up to 100% as compared to the control due possibly to the crosslinking effect of binders. In addition to mechanical bonding of needle-punching, the binders provided additional chemical bonding that which held fibres together so that greater force was required to cause tensile failure of the nonwoven assembly. The crosslinking effect of binders resisted slippage of fibers past one another due to the formation of bond points (on fibre-to-fibre crossovers) spread randomly throughout the nonwoven structure which caused restricted fibre slippage in response to applied force and resulted in decrease of elongation at break of studied nonwovens. Generally, there was further decrease in elongation at break with increasing binder level.

Limem and Warner [7] compared thermal point-bonding to same pattern chemical bonding of polypropylene spunbond nonwovens. They reported at least a 60% and 100% increase in fabric specific stress-to-break in the machine- and cross-direction (CD), respectively. There was a corresponding 80% (MD) and 35%(CD) increase in fabric strain-to-break. In current work, compared to needlepunched fabric, there was an average increase of 120% in tensile strength with varied decrease in elongation at break. The highest decrease was measured for Lurapret D 579 (46%) and lowest for Lurapret DPS (13%) . The decrease in elongation compared to study on PP fabrics is owing to inherent structural features of the fabrics. Spunbond fabrics are held together by fusion of fibres where as needlepunched fabrics are constrained by frictional forces. It is pertinent to mention that Limem and Warner [7] used lightly bonded PP spunbond to compare to chemical bonding whereas in current work already needlepunched fabrics were printed and compared for mechanical properties.

The tear strength (Table 4) is closely related to the compactness of the structure, loose structures resist tearing owing to bundling effect of fibres as more fibres would be required to be broken at the same time while in rigid structures fibres are unable to bundle and are relatively easy to break [16]. The increase in the binder concentration resulted in decrease of the tear strength. At 400 g kg^{-1} binder concentration the tear strength slightly increased. This increase may be attributed to back-thickening effect of the print pastes. Unlike wovens, the nonwovens lack periodic structure as they are manufactured directly from fibres and for comparable fibre and fabric parameters exhibit lower bending length. As the binder concentration was increased, the bending length increased as well linked to the crosslinking effect of binders. The crosslinking of binders increased the stiffness and hence bending length. But at 400 g kg^{-1} binder concentration, the bending length decreased again. As the binder concentration increased, the mass density of the nonwovens increased as well. At high binder concentration the mass density increased to such a high extent that the nonwovens wouldn’t bear their own mass and exhibited lower bending length. It may also be associated to paste back-thickening.

Like mechanical properties, the crosslinking effect of binders was apparent in crock fastness of printed nonwovens. The results showed that there was a slight improvement in crock fastness with increase in binder concentration. However at 50 g kg^{-1} pigment concentration, the binder concentration of 200 g kg^{-1} was sufficient. To enhance the probable effectiveness of binders in improving crock fastness, printing was carried out in the presence of a fixing agent (Helizarin Fixer VLF). The nonwovens were printed with Helizarin Green FF-BT 50 g kg^{-1}, Binder TOW 200 g kg^{-1} and Fixer VLF at 5, 10, 15, 20 and 25 g kg^{-1}, the balance amount being Thickener HIT Plus. The printed nonwovens were dried at 110^{o}C for 2 min. and cured at 160^{o}C for 3 min and 4 min. each. The mechanical properties and crock fastness were measured and the results were presented in Table 5.

Table 5 – Effect of fixer and curing time on crock fastness and mechanical properties

Comparing with the effect of binder, the tensile strength and elongation of nonwovens did not change appreciably while tear strength decreased slightly with increase in fixer amount. Since fixers are multi-functional crosslinking agents such as methylolated melamine, it was likely that akin to binders the crosslinking effect would have resulted in chemical welding of fibres. The bending rigidity increased appreciably with increase in fixer concentration which was another indirect measure of the crosslinking effect of fixer. The higher the stiffness, the lesser the deformation of the nonwovens was expected. The effect of fixer was apparent in the crock fastness of printed nonwovens. The dry rubbing decreased while the wet rubbing improved. The increase in wet rubbing is likely due to the enhanced-crosslinking of binder that resulted in most of the remnant hydrophilic chemical groups in binders being consumed. The fixers could also crosslink hydrophilic groups in the amorphous regions of the fibres, thereby decreasing water absorption. The decrease in dry rubbing might be due to loss of elasticity in binder films. The enhanced chemical crosslinking resulted in stiff films that were more easily worn out or damaged during dry rubbing action. The fixers might also decrease moisture content of the binder films and fibres. Therefore, elasticity of binder films is an important property. Usually polyurethane based binders yield better elastic films than acrylic based binder. Since dry rubbing decreased while wet rubbing improved, the pigment printing might be optimized to get the best possible combination of crock fastness. Such as, with 15 g kg^{-1} Fixer VLF, the dry rubbing was affected a little while there was notable improvement in wet rubbing. The dry rubbing was closely related to the lubrication phenomena of surfaces. One possible solution to improve dry crock fastness is to incorporate a suitable softener into the print paste formulation. The amounts of binder, fixer and softener may be optimized to get the best of both the crock fastness in pigment printed nonwovens.

Disperse Printing

PET nonwovens were printed with Foron Red RD-RBLS, Foron Blue RD-GLN and Foron Golden Yellow RD-2RLN to a range of shade depths. The buildup behaviour and reflection spectra of disperse dyes were presented in Figure 1 and Figure 2, respectively.

Figure 1 – Buildup of disperse dyes on PET needle-punched nonwovens

The disperse dyes exhibited excellent build-up and shade uniformity on needle-punched PET nonwovens. Foron yellow exhibited the highest build-up, the maximum colour strength being achieved at 20 g kg^{-1}. The maximum K/S for Foron red and blue were recorded at 75 g kg^{-1} and 50 g kg^{-1}, respectively. The fixation of disperse dyes is generally carried out continuously at high temperature in a hot flue chamber. Two phenomena took place during thermofixation. At high temperature (200^{o}C) the disperse dyes were sublimed into the vapours state while the fibres became glassy i.e. the fiber structure became more accessible due to excessive molecular motion of the polymer chains and pendent side groups. Due to substantivity, the dye molecules adsorbed and then diffused into the amorphous regions of the fibrous matrix. Any surface-deposited dye was removed by treating nonwovens in hot aqueous alkaline-reductive medium. The diffusion of dye molecules depends on a number of dye, fiber and process factors. The dye parameters may include dye chemistry, physical state, dipole moment, molecular mass and stereochemistry. The fiber parameters may include the surface area, porosity of the fibrous structure, glass transition temperature (T_g). The process parameters include dyeing profile, dyebath concentration gradient, dyeing temperature, humidity, dyeing time. In the present study these parameters were not studied as fiber and the disperse dyes were the same as would be used in the dyeing of PET woven or knitted structures. In nonwovens, the structural of fabrics directly prepared from fibres could be useful as Burkinshaw et.al reported that owing to high surface area of the nonwovens, dyeing took place quickly as compared to dyeing of knitted and woven structures [3].

Table 6 – Colorimetric and fastness properties of disperse printing on nonwovens

The colorimetric and fastness properties of disperse dyes were measured and presented in Table 6. It was evident that the lightness (L^*) decreased with increase in shade depth. The decrease in lightness was due to the absorption of incident light. The Foron red dye became greener-yellower; Foron blue became redder-yellower while Foron yellow became greener-bluer as the shade depth increased. Theoretically, the reflectance spectra of dye must have been changed only in the absorption region but practically light absorption took place over the whole visible region resulting in variations in tone and chroma of the same dyes. On industrial scale changes in colour coordinates or tone with shade depth are helpful in predicting and correcting shade during colour matching. The wash, crock, sublimation and light fastness of the dyed nonwovens were also measured. There was a slight decrease in wash and crock fastness as the shade depth increased while sublimation and light were little affected. Little change in fastness properties showed that studiesd nonwoven fabrics don’t appreciably affect the fastness properties.

Needle-punched PET nonwovens were successfully printed with good build-up and shade solidity. Unlike pigment printing, disperse printed nonwovens were subjected to alkaline-reductive conditions to remove surface deposited dye particles. Since the fibrous assemblies can be distorted in hot aqueous environment, due care needs to be taken for processing nonwovens in such conditions [14,15]. In the laboratory work, nonwovens were subjected to little tension and therefore no appreciable distortion was observed in the nonwoven structures. However, when the same nonwovens would be processed on industrial scale machinery, tension shall preferably have to be controlled to ensure the structural integrity of nonwovens.

Conclusion

The needle-punched nonwovens were characterised of exhibiting variations in mass density that affected the physical characteristics. The pigment printed nonwovens exhibited excellent shade solidity and notably improved tensile strength of the fibrous structure. The pigment printing was successfully carried to improve the aesthetics. Since there are no after-treatments, pigment printing of nonwovens is advantageous as printing could be employed as chemical bonding technique for bonding webs or could be used as a finishing treatment on already bonded fabrics. The disperse printing of nonwovens yielded excellent results in terms of colour strength and shade solidity. Since disperse printing required reduction-clearing which was carried out in hot aqueous environment, the structural integrity could be maintained by employing a low fabric tension process.

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Future Work

Future work may be carried out to investigate the effect of textile wet processing machinery and process conditions on the structure-property relationship of nonwovens. The results might be helpful in suggesting which textile machine suits the best for processing nonwovens or how the existing machinery may be modified to cater needs of the nonwovens industry. The best combination of dry and wet crock fastness may be achieved by optimizing binder, fixer and softener amounts in the print paste formulations.

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Table 1 – Dyes and pigments

Disperse dyes	Pigments
Foron Red RD-RBLS (Archroma)	Helizarin Crimson ECO (BASF)
Foron golden Yellow RD-2RLN (Archroma)	Helizarin Blue FF-N (BASF)
Foron Blue RD-GLN (Archroma)	Helizarin Green FF-BT (BASF)
	Helizarin Violet FF-RT(BASF)

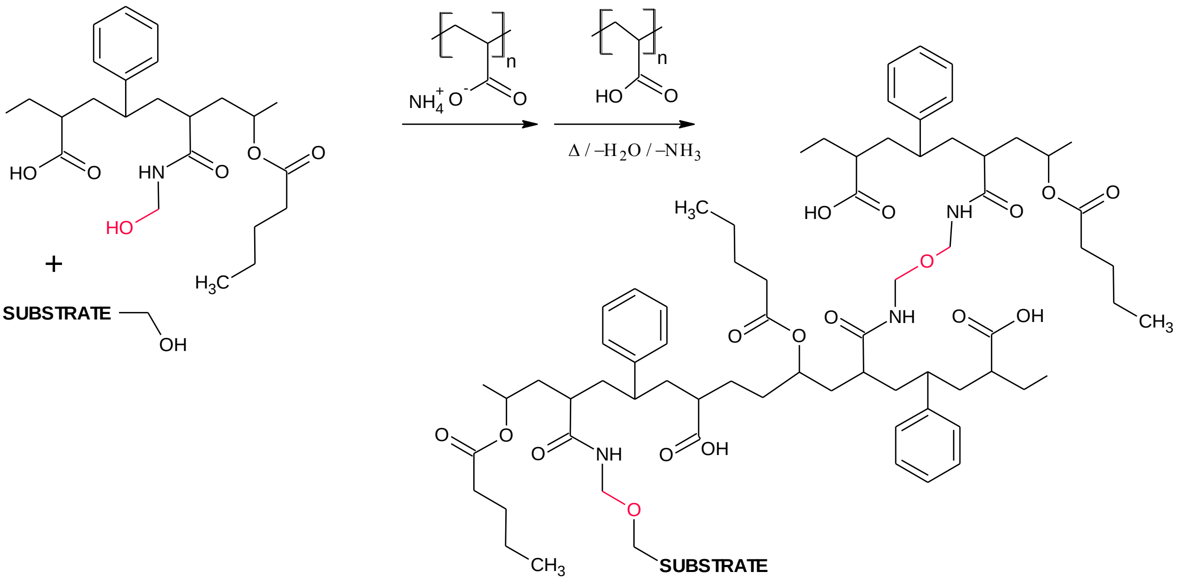
Table 2 – Printing auxiliaries

Name	Chemistry
Lutexal Thickener HIT Plus (BASF)	Anionic high molecular weight vinyl polymer
Helizarin Binder TOW (BASF)	Aqueous dispersion of acrylate polymer
Helizarin Binder FF-SR (BASF)	Aqueous dispersion of acrylate copolymers
Helizarin Fixer VLF (BASF)	Melamine-formaldehyde addition product
Lurapret D 579 (BASF)	Aqueous dispersion based on acrylic esters and acrylonitrile
Lurapret D 2374 (BASF)	Anionic aqueous dispersion based on acrylic ester copolymers
Lurapret DPS (BASF)	Anionic aqueous dispersion based on polyurethane
Lyoprint RD-HT (Huntsman)	Anionic blend of polyacrylic acid and natural polymers

Table 3 – Print properties and crock fastness of pigment printing on nonwovens

Pigments	**Amount** (g/kg)	**Mass density** (g/m^2)	**Print properties**		**Crock fastness**	
			Penetration depth (mm)	Paste add-on (%)	Dry	Wet
Helizarin Crimson ECO	5	80	0.8±0.01	30±4	4-5	4
		140	0.8±0.02	27±3	4	3-4
		200	0.9±0.02	21±1	4	4
	10	80	0.8±0.02	32±4	3-4	3
		140	0.9±0.03	20±2	3-4	3-4
		200	0.8±0.01	17±1	3-4	3
	50	80	0.9±0.02	36±3	2-3	2-3
		140	0.7±0.01	28±2	2-3	2-3
		200	0.9±0.02	22±1	2-3	2-3
	100	80	1.2±0.03	49±4	2	2
		140	0.4±0.01	38±3	2	2
		200	0.9±0.02	29±1	2	2
	150	80	0.6±0.02	60±4	2	1-2
		140	0.7±0.02	40±3	2	1-2
		200	0.9±0.02	23±3	2	1-2
Helizarin Blue FF-N	5	80	0.9±0.03	34±2	4	3-4
		140	1.0±0.02	29±1	4	3-4
		200	0.7±0.01	19±1	4	3-4
	10	80	1.4±0.01	39±2	4	3
		140	1.3±0.03	25±2	4	3
		200	0.8±0.02	22±2	4	3
	50	80	1.2±0.02	42±3	3-4	3-4
		140	1.1±0.03	31±2	3-4	2-3
		200	0.6±0.01	23±2	3	2-3
	100	80	1.4±0.01	47±4	3	2
		140	1.0±0.02	31±3	3	2-3
		200	0.6±0.01	20±2	3	1-2
	150	80	1.8±0.03	75±4	2-3	1-2
		140	0.8±0.01	44±3	2-3	1-2
		200	0.8±0.01	33±3	2-3	1-2

Binder TOW: 200 g/kg, Curing: 160ºC for 3 min.



Scheme 1 – Chemical constitution and schematic crosslinking of textile binders

Table 4 – Effect of various binders on mechanical properties and crock fastness of pigment printed nonwovens

Binders	**Amount** (g/kg)	**Tensile properties**		**Tear strength** (N)	**Bending rigidity** (mm)	**Crock fastness**	
		Strength (N)	Elongation (%)			Dry	Wet
Control	**-**	52.4±4.2	74.4±7.3	43.1±9.1	35.6±3.5	-	-
Helizarin Binder TOW	200	110.0±2.2	55.1±5.8	23.3±4.8	68.8±7.6	4	3
	300	116.1±2.5	49.6±2.2	15.5±2.3	75.9±6.1	4	3-4
	400	113.4±2.0	56.4±1.0	16.8±2.4	55.4±3.1	4-5	3-4
Helizarin Binder FF-SR	200	113.7±3.0	59.9±2.4	23.4±4.5	59.4±9.5	3-4	3
	300	113.3±5.1	54.9±4.9	17.2±2.5	74.5±9.3	4	3
	400	118.4±7.9	63.6±4.9	20.2±2.4	55.9±6.9	4	3
Lurapret D 579	200	119.9±5.5	41.0±3.7	15.7±2.4	77.2±6.3	3-4	3
	300	124.4±10.0	38.4±3.8	10.0±2.0	79.7±7.8	3-4	3-4
	400	117.3±6.2	40.1±2.5	14.6±2.0	64.0±7.7	4	3-4
Lurapret D 2374	200	101.0±6.4	56.9±5.6	18.6±2.3	66.4±9.9	3	3
	300	107.0±9.9	47.8±6.7	14.9±2.0	72.9±9.9	3-4	3-4
	400	112.5±9.9	57.3±7.2	13.9±1.9	55.0±3.8	3-4	4
Lurapret DPS	200	111.2±6.4	67.3±2.5	23.7±4.2	75.3±8.2	3-4	1-2
	300	121.1±5.4	62.4±6.2	20.1±4.0	77.7±11.1	3-4	1-2
	400	117.8±9.3	64.1±6.1	25.5±4.1	64.6±10.6	3-4	1-2

Helizarin Blue FFN: 50g/kg, Curing: 160°C for 3 min., GSM: 80 g/m^2

Table 5 – Effect of fixer and curing time on crock fastness and mechanical properties

Fixer VLF (g/kg)	**Time** (min.)	**Tensile properties**		**Tear strength** (N)	**Bending rigidity** (mm)	**Crock fastness**	
		Strength (N)	Elongation (%)			Dry	Wet
Control	-	172.9±22.0	55.8±6.6	36.9±9.5	118.3±2.7	3-4	2-3
5	3		57.5±10.3	33.8±9.2	125.7±2.8	3	3
10		164.9±14.1	50.3±3.0	36.2±6.3	137.1±4.9	3	4-5
15		152.4±12.8	43.6±3.9	34.9±6.0	143.4±4.1	3-4	4
20		159.3±11.4	43.4±7.3	30.1±4.5	149.4±3.3	2-3	4-5
25		161.1±11.5	49.8±5.8	28.7±2.9	155.8±2.4	2-3	4-5
Control	-	178.1±13.9	55.8±6.7	36.7±5.1	141.4±2.5	3-4	2-3
5	4	202.4±7.94	53.7±2.3	38.1±6.8	148.8±2.0	3	4
10		171.5±12.2	50.5±4.4	36.2±4.4	151.0±1.5	3	4
15		174.7±9.7	52.5±6.9	34.9±3.5	164.7±8.2	2-3	4
20		177.0±14.9	45.2±7.4	28.3±2.8	173.0±0.8	2-3	4
25		152.9±9.5	38.6±4.9	28.7±3.0	immeasurable	2-3	4-5

Helizarin Green FF-BT: 50 g/kg, Binder TOW: 200 g/kg, Curing: 160ºC, GSM: 200 g/m^2

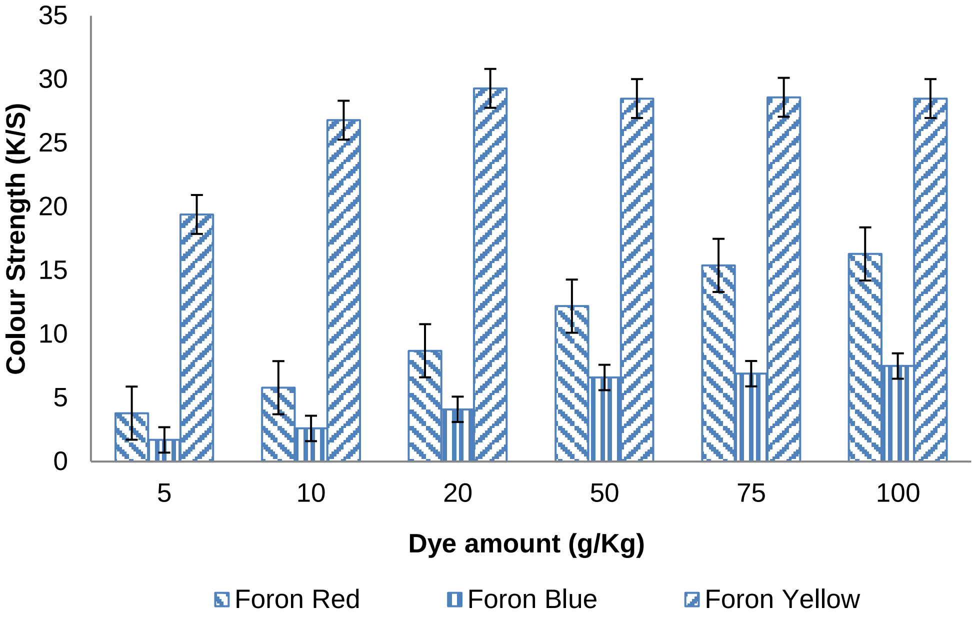


Figure 1 – Buildup of disperse dyes on PET needle-punched nonwovens

Table 6 – Colorimetric and fastness properties of disperse printing on nonwovens

Disperse dyes	**Amount** (x g/kg)	**Colorimetric properties**			**Fastness properties**								
					Wash					**Crock**		**Sublimation**	**Light**
		L^*	a^*	b^*	Color change	Staining				Dry	Wet	(@220ºC, 1min.)	
						PET	Acet	Nylon	Wool				
Foron Red RD-RBLS (λ_{max} 650 nm)	5	40	41	2	4	4-5	4	3-4	3-4	4-5	4	5	6
	10	36	46	6	4	-	-	-	-	-	3	-	-
	20	33	45	9	3	-	-	-	-	-	-	-	-
	50	30	44	11	3-4	-	4-5	-	-	-	-	-	-
	75	27	41	11	-	-	4	-	-	-	-	-	-
	100	27	40	12	-	-	4	-	-	-	2-3	-	-
Foron Blue RD-GLN (λ_{max} 450 nm)	5	31	1	-29	4	4	4	3-4	3-4	-	4	-	-
	10	27	2	-27	4	-	-	-	-	-	4	-	-
	20	22	3	-24	-	-	-	-	-	-	4	-	-
	50	18	4	-19	-	-	-	-	-	-	3-4	-	-
	75	18	4	-19	-	-	4-5	-	-	-	3-4	-	-
	100	17	4	-17	-	-	4	-	3	-	3	-	-
Foron Golden Yellow RD-2RLN (λ_{max} 550 nm)	5	55	33	61	4-5	4-5	4	4	4	-	4	-	-
	10	47	43	55	-	-	-	3-4	-	-	-	-	-
	20	41	45	46	-	-	-	-	-	-	-	-	-
	50	33	43	35	-	-	3-4	-	3-4	-	3-4	-	-
	75	31	42	32	-	4	3	3	-	-	-	-	-
	100	32	42	31	4	4	3	3	-	-	-	-	-

pH 5, Drying 110ºC, Thermofixation 200ºC for 1 min., GSM: 200 g/m^2