Analysis of UV-cured and Thermally-cured Inkjet Printed Poly (Lactic Acid) Fabrics

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Abstract

Inkjet printing of Poly (Lactic Acid) (PLA) fabrics using UV-curable inks is of interest due to the thermal sensitivity of PLA and the opportunity for "ambient" temperature curing of the surface ink. In this study, PLA fabrics were printed with Mimaki LH - 100, LF - 140 and LF - 200 UV-curable inks and Mexar thermal inks using a Mimaki UJF - 3042 LED UV inkjet printer and R-Jet 4 DTG printer, respectively. The prints of CMYK colours printed with UV-curable and thermal inks were cured at ambient temperature using a UV LED device and at 150°C for 5 minutes using heat press machine, respectively. The colour fastness properties, Kawabata Evaluation System (KES-F) mechanical properties and bursting strength of the printed samples were evaluated and surface topography using Scanning Electron Microscopy (SEM) analysed. UV-curable inkjet printed PLA fabrics provided better or similar colour fastness and better handle than that of thermally-cured inkjet printed PLA fabrics. The curing condition appeared not to have any effect on the bursting strength of UV curable inkjet printed fabrics; however bursting strength of thermally-cured prints reduced significantly after curing.

1. Introduction

The application of inkjet technology for textile printing has increased significantly in recent years [1], because of its advantages over traditional printing methods such as mass customisation in the production process, reduction in downtime and sampling cost, less waste output and lower usage of water and chemicals [2,3]. Similarly, UV curing of polymers has found a number of applications in the printing and surface coatings industry and is already well established in terms of traditional printing processes such as lithography, flexography and screen printing on papers and hard substrates [4]. Specifically, the use of UV curing technology in printing has been increasing significantly because of a number of advantages such as the low energy consumption, short start-up period, fast and reliable curing, low environmental pollution, curing at room temperature, space savings etc.[5]. Moreover, thermal-curing of pigment printed fabrics not only involves higher fixation temperature but also provides a relatively stiffer handle, poor rubbing fastness and reduced strength [6]. Therefore, there has been growing interest to incorporate UV curing processing with the technology of inkjet printing so that the benefits of these two technologies could be exploited. The piezoelectric Drop-On-Demand (DOD) UV curable inkjet has experienced double digit growth on paper and hard substrates because of the advantages offered by the integration of the inkjet and UV curing technology [7]. However, careful attention is required in order to integrate these two technologies together for textiles application, as UV-curing has presented technical performance problems such as poor rub fastness and poor handle of the fabrics, as well as low curing efficiency of the finish [8].

PLA fibres have generated great interest as a green material due to its natural-based origin and biodegradability. However, the wet and dry processing of PLA fabrics is typically carried out at low temperature because of its relatively low glass transition temperature and melting point, as well as potential degradation at higher temperature and treatment time [9]. Therefore, inkjet printing of PLA fabrics using UV-curable inks is of interest due to the "ambient" temperature curing of the surface. In this study, PLA fabrics were printed with Mimaki LH - 100, LF - 140 and LF - 200 UV-curable inks and Mexar thermal inks using a Mimaki UJF-3042 LED UV inkjet printer and R-Jet 4 DTG printer respectively. The prints of CMYK colours printed with UV-curable inks and thermal inks were cured at ambient temperature using a UV LED device and at 150°C for 5 minutes using heat press machine respectively. The colour values, KES-F mechanical properties and bursting strength of the printed samples were evaluated and surface topography using Scanning Electron Microscopy (SEM) analysed.

2. Experimental

2.1 Materials

In this investigation, 100% PLA single jersey knit pique fabric, 268g/m^2, purchased from Valuable Enterprise, Taiwan, was scoured at 60°C for 20 minutes in a solution containing 2 g/L soda ash and 0.5 g/L Kieralon Jet B Conc and air dried. LH - 100, LF - 140 and LF - 200 UV-curable inks of Cyan (C), Magenta (M), Yellow (Y) and Black (K) colours were supplied with Mimaki UJF - 3042 UV LED flatbed printer. Hybrid Services Ltd, Crewe, UK, Mimaki's exclusive distributors in the UK and Ireland, supplied UV-curable inks and provided facilities to print the fabric at their premises. 'Mexar' thermal-inks of Cyan, Magenta, Yellow and Black colours were kindly donated by Mexar inkjet solutions, UK and they also provided facilities to print thermal inks at their premises.

2.1 Methods

A Mimaki UJF - 3042 UV LED flatbed printer was used to print UV curable LH - 100, LF - 140 and LF - 200 CMYK inks onto PLA fabrics. A solid pattern of 20cm×20cm area printed for each sample of CMYK colours and UV-cured subsequently using the overhead UV curing LED device. A R-Jet 4 DTG printer was used to print 'Mexar' thermal inks onto PLA fabrics, and printed fabrics were subsequently dried at 90°C for 5 minutes using a heat press machine and cured at 150°C for 5 minutes using a Werner Mathis laboratory dryer.

Colour fastness to washing was carried out according to ISO 105 C06 C2S, by treating the printed fabrics in a solution containing 4 g/L ECE detergent with 1 g/L sodium perborate and 25 stainless steel balls, adjusted to pH 10.5, at 60°C for 30 minutes [10]. The colour strength *(K/S)* was calculated from reflectance measurements using following Kubelka-Munk equation (equation (1)):

$$(K/S)_\lambda = (1-R_\lambda)^2/2R_\lambda \qquad \ldots\ldots (1)$$

Where *K* is the absorption co-efficient, *S* is the scatter co-efficient and *R* is the reflectance expressed as a fractional value at wavelength λ_{max}. A Datacolor Spectroflash 600 was used to measure *K/S* and CIE *L*a*b** values and the mean value was calculated from the average of four measurements. Colour measurements were taken before and after washing of printed samples and colour difference values were also noted.

The bursting strength of the pigment printed samples was measured using a TruBurst Burst Strength Tester Model 500/610 according to BS EN ISO 13938-2:1999 and the Kawabata Evaluation System for Fabrics (KES-F) was used to determine the mechanical and surface properties of unprinted and printed PLA fabrics. The samples (20×20cm) were conditioned for 24 hours at 20°C and 65% relative humidity prior to analysis. The surface topography of untreated and pigment printed PLA fabrics (before and after wash) was analysed using a Philips XL 30 field emission scanning electron microscope.

3. Results and Discussions

3.1 Colour Analysis

The colour fastness to washing of UV-cured and thermally-cured inkjet printed PLA fabrics are shown in Table 1. The colour fastness to washing of UV-cured inkjet printed PLA fabrics was found to be better or similar to that of thermally-cured inkjet printed PLA fabrics. The wash fastness of LH - 100 inks was found to be acceptable with a rating of 3 to 4 for cyan, magenta and yellow inks, which is better than that of LF - 140, LF - 200 and Mexar thermal inks. An UV curable ink formulation typically contains reactive monomers, oligomers, photoinitiator, colourants and additives such as surfactants and inhibitors. The cross-link density of the polymer films can be increased by increasing the functionality of the acrylates, resulting in less flexible, harder films that have high resistance to solvents, abrasion, and scratches [7]. As LH - 100 inks contain acrylates of higher functionalities in their formulations than that of LF - 140 and LF - 200 [11], it is therefore likely that they would produce higher density of shorter cross-links, resulting in overall better entrapment of the pigments [7].

Table 1. Colour Fastness to Washing Properties of UV-Cured and Thermally-cured Inkjet Printed PLA Fabrics

Inks Types		Cyan	Magenta	Yellow	Black
UV	LH - 100	3	3-4	3	2
	LF - 140	2-3	2-3	4	2
	LF - 200	2	2-3	3	2-3
Thermal	Mexar	2	2-3	3-4	3

The colour strength *(K/S)* of Cyan and Magenta UV inks was found to be higher than that of thermal inks which is the opposite for the yellow and black inks. LH - 100 inks, illustrated in Figure 1, provided higher colour strength than the inks of other types because of higher acrylates functionalities. However the colour strength for all inks reduced significantly after a single washing cycle, demonstrating the lower wash stability of the prints. Therefore the colour difference between unwashed and washed printed samples was found to be higher; but LH - 100 inks provided less colour difference (*ΔE)* values than other inks which could be again because of higher cross-link densities produced by LH - 100 inks.

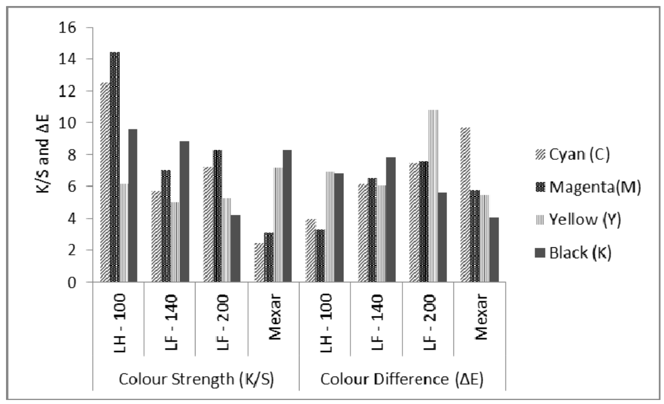

***Figure 1**. Colour Strength (K/S) and Colour Difference (ΔE) Values of UV-Cured and Thermally-cured Inkjet Printed PLA Fabrics*

3.2 Bursting Strength

The bursting strength of PLA fabrics reduced significantly after thermal-curing of Mexar inks at 150°C for 5 minutes due to likely increased brittleness of the three dimensionally linked fabric/binder structure at high curing temperature. Our previous study on screen pigment printed PLA fabrics also suggested a reduction in bursting strength of printed fabrics with the increase of curing temperature [6]. In addition it was found in a study by Yang and Sun[12], that the strength of PLA reduced significantly with the heat treatment higher than 130°C. In contrast, no significant effect observed on bursting strength of UV-cured inkjet printed PLA fabrics due to ambient temperature curing of printed fabrics.

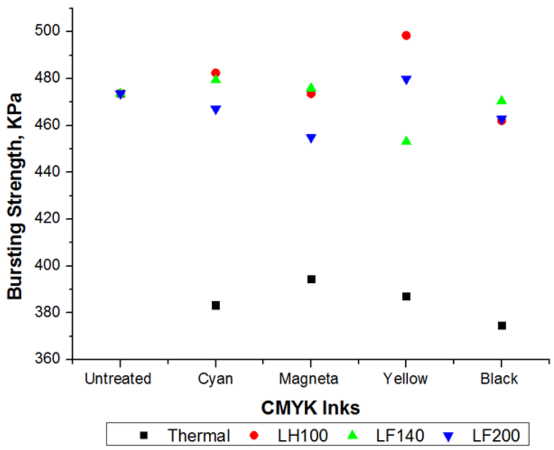

***Figure 2.** Bursting Strength of UV-Cured and Thermally-cured Inkjet Printed PLA Fabrics*

3.3 Kawabata Analysis (KES-F)

The Kawabata Evaluation System indicated that the extensibility (EM %) of PLA, Figure 3, reduced significantly after printing with both thermal and UV curable inks. The effect was more

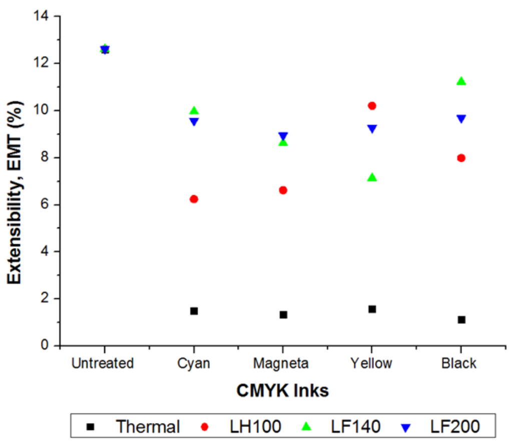

***Figure 3.** Extensibility (%) of UV-Cured and Thermally-cured Inkjet Printed PLA Fabrics*

significant for thermal inks because of higher fixation temperature; whereas the reduction in extensibility was moderate for UV inkjet printed fabrics. Thermal-curing provided higher degree of cross-linking and rigid inter-fibre bonding which restricted the extensibility of printed fabrics. Moreover, the cross-linking of the acrylates deposited through printing upon exposure to UV light reduced the extensibility of the fabrics, and the coating of hard LH - 100 inks on the surface of PLA fabrics imparted restricted fibre flexibility [7]; thus provided less extensibility than other types of inks. After a single washing cycle, the extensibility recovered to the similar level as that of the unprinted sample, which also indicates the poor wash stability of the prints on the fabrics.

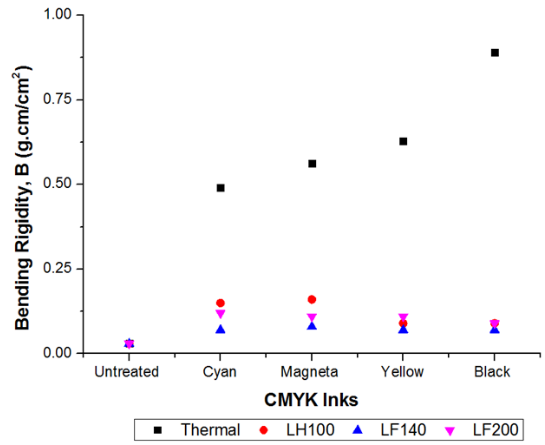

***Figure 4.** Bending Rigidity of UV-Cured and Thermally-cured Inkjet Printed PLA Fabrics*

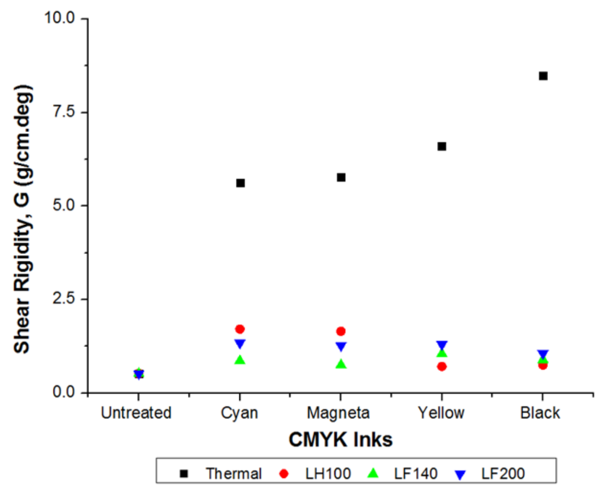

***Figure 5.** Shear Rigidity of UV-Cured and Thermally-cured Inkjet Printed PLA Fabrics*

In contrast, the bending rigidity (B) and shear rigidity (G) of Mexar thermal inks, illustrated in Figure 4 and Figure 5, increased significantly with the application of printing inks and their subsequent fixation by thermal curing. The bending properties of a fabric are influenced mainly by inter-fibre and inter-yarn forces, which were limited by increased cross-linking of thermal inks at higher temperature. The bending rigidity (B) and shear rigidity (G) for UV-cured inkjet printed fabrics also increased however the effect was much lower than thermal inks. The effect of curing on shear rigidity and bending rigidity of LF - 140 inks printed PLA of CMYK colour was lower than that of printed with other types of inks .

3.3 Surface Morphology

SEM micrographs of unprinted and printed PLA fabrics are illustrated in Figure 6 - 8. SEM images of both UV-cured and thermally-cured inkjet printed PLA fabrics indicated the deposition of ink droplets onto the fibre surface. Inter-fibre bonding achieved through photo-polymerisation of UV inks and thermal-crosslinking of Mexar inks was also observed. After a 5A washing of printed fabrics, the inter-fibre bonding was still observed but some surface film damage was detected, Figure 8.

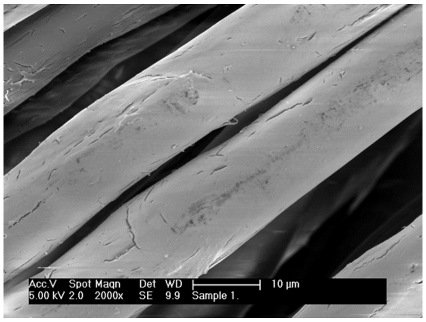

Figure 6. *SEM Micrograph of Unprinted PLA Magnification X2000*

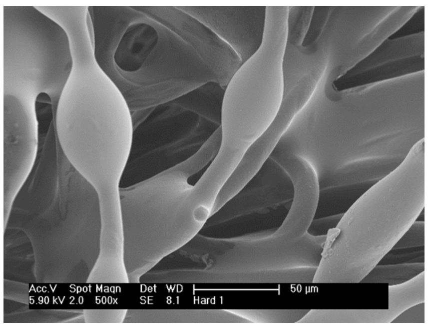

Figure 7. *SEM Micrograph of Inkjet Printed UV-cured PLA. Magnification X500*

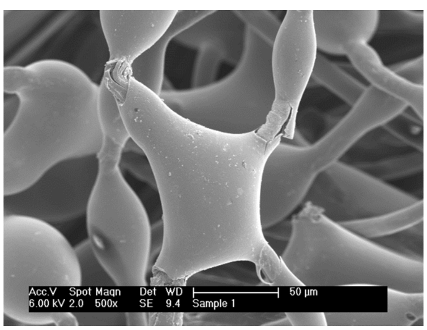

Figure 8. *SEM Micrograph of After Washed Inkjet Printed UV-cured PLA Magnification X500*

4. Conclusions

Inkjet printing of heat sensitive PLA fabrics using UV inks and thermal inks is reported in this paper. UV-cured inkjet printed PLA fabrics offered good colour fastness properties, handle and less degradation to curing process; whereas thermal curing of PLA fabrics involved significant reduction in the burst strength of the fabrics. UV-curable inkjet printing could therefore be a possible solution to the problem of high temperature sensitivity of PLA fabrics.

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