Laser Peri-Dyeing for Agile Textile Design: Implementing Laser Processing Research within the Textile Industry

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Abstract A laser dyeing technique named peri-dyeing, has been developed showing potential for efficient and agile textile surface patterning and coloration. After industrial interest in the technique for manufacturing and customization of textile products, this research aimed to identify and pursue new opportunities to implement and exploit the laser peri-dyeing technique within different textile sectors, focusing on the potential to apply peri-dyeing directly to garments, fashion and upholstery fabrics. This paper details the initial findings relating to industrial exploitation of the laser dyeing technique within four distinct sectors of the textile industry, to identify and pursue opportunities to implement laser peri-dyeing for textile products and their associated supply chains. Through performance testing and design prototyping, this paper reports on the suitability of the technique for nylon /elastane sportswear and swimwear fabrics and narrowband textile components. The laser peri-dyed samples were shown to meet with commercial textile durability and performance standards, enabling digital design innovation and direct-to-garment processing opportunities. The paper discusses opportunities for customization in the manufacture of finished textile goods and the potential for sustainability benefits including reduced resource consumption through efficient use of water, energy and a responsive distribution of goods.

***Keywords*— CO_2 Laser, Surface Design, Textile Industry, Sustainable Coloration.**

I. Introduction

The demand for more efficient, environmentally sustainable and quick-to-market textile and fashion goods has increased the demand for flexibility and responsiveness within manufacturing systems and supply chains [1,2]. This can be referred to as agile manufacture: production systems that enable companies to meet market demands rapidly and responsively [3]. Further to this, an increasing offering of production on-demand business models can be seen via online and bespoke retailing services [4,5]. In a shift from advance bulk ordering, these companies produce goods to order according to the demand of their customers, thereby reducing stockholding and subsequent waste. Digital technologies have been cited as one way to increase agility in supply chains [6] by allowing late-stage design decisions and flexibility to change complex designs without complicated or costly set up.

Laser technology provides an example of a digitally-led processing system. Lasers operate a dry energy efficient system that can be controlled precisely via computer software. Research has shown that lasers can be used to enhance dyeing [7,8,9], patterning [10,11,12] molding [12], and engraving [13] for aesthetic and functional textile finishes. Industrial laser equipment exists that allows accurate processing of textile lengths and fully finished garments [14]. However, the use and uptake of lasers in the textile and clothing industry is predominately associated with fading of denim [15] and cutting applications [16]. Previous laser pre-treatment techniques have proven to have a damaging effect on fibre strength [17]. Therefore, examples of the industrial development of laser dyeing and alternate laser finishing procedures beyond research stage are rare.

A laser dyeing technique named peri-dyeing, has been developed showing potential for efficient and agile textile surface patterning and coloration [12]. Peri-Dyeing is a laser dye fixation method for textiles, developed during an Arts and Humanities Research Council, UK funded research project from 2012-2015. The technique allows the dye reaction and diffusion to take place at the point of laser material interaction. Therefore, allowing efficient, targeted coloration and surface patterning of textile materials. The technique showed the potential to make significant savings in energy, water and dye use in comparison with conventional textile coloration and patterning processes. In addition, the digital peri-dyeing process suggests alternative manufacturing and distribution flows that may allow for a more precise, responsive approach to market demands potentially reducing waste stock and enabling a more efficient distribution of goods. By enabling localized and on-demand coloration and surface modification for aesthetic appearance and functionality, environmental and cost benefits were predicted.

After industrial interest in the technique for manufacturing and customization of textile goods, this research aimed to identify and pursue new opportunities to implement and exploit the laser peri-dyeing technique within different textile sectors, focusing on the potential to apply peri-dyeing directly to garments, fashion and upholstery fabrics. This paper details the initial findings relating to industrial exploitation of the laser dyeing technique within four distinct sectors of the textile industry, to identify and pursue opportunities to implement peri-dyeing for textile products and their associated supply chains. In addition, it aims to assess the permanence and durability of the coloration process on chosen materials through commercial performance testing procedures.

This paper summaries the initial findings of ongoing work carried out with three of the four industry partners, building a case for further investment into the laser peri-dyeing technique for apparel and sportswear.

II. Methods and Procedures

A. *Peri-dyeing*

Peri-dyeing is a laser dyeing technique that allows intricate targeted surface design of textile substrates. Dye diffusion and reaction takes place at the point of interaction between the laser and textile material. Previous research has evidenced laser peri-dyeing as capable of producing photographic quality graphics, and multicoloured surface design effects on synthetic fabrics for sportswear textiles and applications [18]. The non-contact laser set up allows precision detail to be achieved on three-dimensional textile surfaces, such as textured fabrics or finished garments.

Using standard dyestuffs and auxiliaries, a commercial dye recipe provided by one of the industry partners for a solid black dye shade was used. The aqueous dye liquor, containing black, yellow and brown dyestuffs was applied to the surface of textile samples immediately followed by laser irradiation according to previously determined optimal processing conditions for laser peri-dyeing.

The laser used for this research was a Synrad carbon dioxide (CO_2) source laser. An infrared Laser was chosen to harness its photothermal properties to induce dye fixation and diffusion on textile substrates (peri-dyeing). All experiments were carried out with the laser beam in focus on the surface of the textile substrate.

B. *Industry Consultation*

Focusing on knowledge sharing activities with industry, consultation with designers and manufacturers in four textile manufacturing sectors (fashion fabrics, upholstery fabrics, fashion garments and sportswear) was used to identify relevant products and associated design and manufacturing supply chains. This paper focuses on textiles for fashion, sportswear and narrowband textile components. Workshops were organised with each of the project partners to identify key opportunities for implementing laser peri-dyeing techniques within current and emerging product and market areas to facilitate more responsive approaches, technical innovation and areas for environmental improvement.

C. *Design Prototyping*

Computer aided designs were created according to industry partner requirements and converted to greyscale raster or vector files for laser processing using Winmark software. CAD controlled graphics or all over processing for solid colour was applied to chosen textile and garment samples using the laser peri-dyeing technique.

D. *Materials*

This paper presents a selection of the performance testing results on nylon textiles provided by the industry partners including: a 16mm wide, 85% nylon, 15% elastane textile narrow band strap, and a knitted 80% nylon, 20% elastane fabric.

A wider range of nylon, polyester and wool commercial fashion, upholstery and sportswear fabrics and garments provided by the industry partners were used for design sampling as shown in Fig. 1.

E. *Colour Fastness to Rubbing*

Colour fastness to rubbing was determined by the BS EN ISO 105-X12: 2002 standard test method. Test samples were rubbed with a rubbing cloth using a crockmeter, which provided a constant rubbing pressure of 9N. The staining of the rubbing cloths and any colour change on the test specimen were assessed using the grey scale method. (BS EN ISO 105-A02/ A03: 1993) A value from 1 to 5 is awarded using the appropriate grey scales, where 5 indicates no loss of colour or no staining.

F. *Colour Fastness to Washing*

The effect of washing on colour fastness of the laser peri-dyed samples was determined by attaching a multi-fibre strip to each sample, followed by washing with ECE phosphate reference detergent (B) at 50°C for 30 minutes. After rinsing and drying, colour change of the fabric sample and the staining on the adjacent fabric were assessed by comparison to the original fabric using the greyscale method.

G. *Washing Stability*

To determine the dimensional stability after washing, an array of equally spaced of dots was marked on the laser peri-dyed and untreated control samples. The samples were then washed at 50°C for 30 minutes using ECE phosphate reference detergent (B) in a Dynawash Duo washing machine. The marked dots were measured before and after washing and the difference was calculated to provide the percentage shrinkage.

H. Stretch Modulus

A Tinius Olsen H5KT Tensile Tester was used to provide the stretch modulus of laser peri-dyed and untreated control samples. Each sample was clamped to the tensile tester to be stretched and relaxed twice. The device recorded the force applied to the fabric and the resulting extension to calculate the modulus of the tested specimens in gram-force (gf).

I. Chlorine Durability

Untreated control samples and laser peri-dyed samples were prepared with one of the wash off treatments a, b, c, or d. The samples were tested in their own container containing chlorinated water at a concentration of 100mg chlorine per litre of water for 24hrs. After 24 hours, the samples were rinsed, air dried and assessed for colour loss using the greyscale method.

J. Washing Durability

Samples were washed using ECE phosphate reference detergent (B) in a Dynawash Duo washing machine, agitated with ball bearings at 50ºC for 5 hours. After 5 hours, the samples were rinsed, air dried and assessed for colour loss using the greyscale method.

III. Results and Discussion

A. Opportunities to Implement Peri-dyeing on Textile Goods

Consultation and collaboration with the industry partners via project meetings and company visits allowed the laser *peri-dyeing* research to be introduced to design and product development teams and to establish appropriate materials, product types, suggested uses and common problems with current manufacturing systems that the laser peri-dyeing technique had potential to address. In addition, discussions took place to establish the most appropriate opportunities to implement the technique within the company supply chain or production line.

Based on industrial interest sampling was carried out to test the suitability of the laser peri-dyeing process on a range of polyester and nylon fabric constructions including: narrowband fabrics; a range of textiles for apparel fabrics, knitted intimate apparel fabrics; and a range of performance sports and swimwear fabrics. The sampling examined all-over dyeing, intricate surface pattern designs and multicolour ombre design effects and neon coloration on the chosen substrates as shown in Fig. 1.

Fig. 1. Laser peri-dyed design and coloration effects on: intimate apparel polyester fabrics; nylon-elastane knitted sportswear fabrics; and narrow band nylon-elastane straps.

B. Performance testing of Peri-dyed prototypes

Development and performance testing of peri-dyed prototypes was performed in collaboration with the project industry partners. Prototype garments and fabrics were selected and laser peri-dyed to confirm the viability of the process for each textile sector. Greige fabric and garment samples supplied by the industrial partners were laser peri-dyed according to design requirements identified during consultation, covering a range of fibre types, fabric constructions, colour palettes and patterns. These prototypes were assessed in terms of their product performance including standardized textile testing for colour fastness, durability and stretch modulus. The results are presented in Table 1.

Fastness to washing and rubbing results for the laser peri-dyed nylon / elastane specimens all fell within accepted commercial tolerances. While the dimensional stability of the peri-dyed samples showed an improvement: shrinkage after washing was reduced on the laser peri-dyed samples compared to the untreated control.

Accepted commercial tolerances for stretch modulus for the treated fabrics lie between 800gf and 1450gf. The tested specimens produced commercially acceptable modulus results that fell within this range. The change in modulus compared to the undyed untreated control sample was noted by industrial partners as consistent with expected changes that would occur during conventional dyeing procedures.

Peri-dyed nylon-elastane knitted swimwear samples were laser peri-dyed and tested for wash and chlorine durability. These tests provide harsh conditions for the test specimens to emulate extended conditions of washing and wearing in chlorinated water. The results, shown in Table 1, showed a colour change score of 4 using the greyscale method meeting with commercially acceptable standards.

The testing results on peri-dyed nylon-elastane samples evidenced the technique as a suitable coloration method for sportswear textiles and textile components that met with industrial and commercial performance standards.

TABLE I
PERI-DYED NYLON PERFORMANCE TESTING RESULTS TABLE

Test		Untreated nylon	Laser peri-dyed nylon
Colour fastness to washing	acetate	-	4/5
	cotton	-	4/5
	nylon	-	4
	polyester	-	4/5
	acrylic	-	4/5
	wool	-	4/5
Colour fastness to rubbing	staining	5	5
	colour change	5	5
Washing stability (% shrinkage)		-2.9	-2.3
Stretch modulus (gf)		822	940
Washing durability		-	4
Chlorine durability		-	4

Test results are given as scores out of 5 unless otherwise specified.

C. *Opportunities to introduce peri-dyeing within the production cycle*

Through consultation with industry and design prototyping activities, the work has identified four opportunities to introduce peri-dyeing into the textile production cycle as shown in Fig. 2.

By reducing the number of wet pre-processing stages required at textile construction stage, laser peri-dyeing has the potential to offer combined coloration and design effects with improved efficiency through water and effluent reduction. As an alternate dye patterning process, laser peri-dyeing could apply digitally generated precision surface design on textile lengths in place of conventional textile print processes. As evidenced, the peri-dyeing process allows simultaneous dyeing and surface patterning, digital precision and the ability to apply colour designs direct-to-garment and across multicomponent constructed textile goods. This offers the opportunity for highly engineered garments or fabric specific coloration and patterning providing creative freedom and eliminating the waste from lining-up patterns and colour during garment assembly.

Dyeing is currently the most resource intensive aspect of garment manufacture but the laser peri-dyeing process has the potential to reduce this through savings in energy, water, chemical use and subsequent effluents during dyeing and surface patterning and also in terms of buying and distribution. Greige (non-dyed) garments could be stockpiled and laser peri-dyed on demand in response to specific market needs and trends. This would allow buyers the opportunity to call-off specific colours and designs at a reduced time to market, resulting in significantly changing retail buying behaviour from that of bulk buying to specific responsive buying, in doing so, it has potential to reduce waste stock, and enable a more effective distribution of goods.

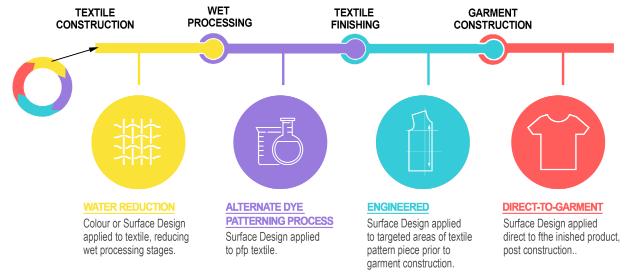

Fig. 2. Opportunities to introduce peri-dyeing within the production cycle.

IV. CONCLUSION

The work to date has evidenced laser peri-dyeing as a controllable and transferable coloration and surface design method for textiles that has relevance across multiple textile sectors (fashion fabrics, upholstery fabrics, fashion garments and sportswear). Garment prototypes and design sampling on commercially relevant fabrics for apparel, narrow band textile components and sportswear, showed proof of suitability, while the durability and elastic properties of the laser treated samples met with commercial performance testing standards.

The research conducted in this study enabled meaningful involvement with industry, through knowledge exchange and creative engagement with stakeholders from different areas of the design and manufacturing supply chain. The production of laser peri-dyed prototypes for multiple textile sectors formed a central vehicle for discussion and collaboration. The research identified opportunities for laser peri-dyeing to be introduced within the textile production and supply chain, from continuous efficient coloration and patterning of textile lengths, to engineered, direct-to-garment processing that may facilitate responsive, agile manufacturing systems and customisation opportunities for short-run production.

It is predicted that supply chain analysis, LCA and user evaluation will further establish the market for the peri-dyeing process by evidencing new creative opportunities and economic advantages, potentially leading to ongoing impact within the textile industry.

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