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Circular Colour: Reusing Colour from Previous Textile Lifecycles in Textile Finishes

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Abstract: Colour is a key component of textiles, drawing interest while also changing with the seasons, which calls for a systemic perspective of its materials circularity in the context of future product lifetimes. To develop new design processes with regenerated cellulose obtained from post-consumer textiles, an exploration of solely undyed materials is not consistent with the reality that established design techniques produce a wide range of multi-coloured textiles. On the other hand, the presence of dyes reportedly impacts on chemical recycling, and conventional dyestuff for cellulosic materials is often oil-based and includes persistent dyestuff made up of unknown chemicals. Keeping the dyes of discarded textiles in a closed loop would replace the need for new dyestuff, reducing the use of water and energy for dyeing and de-dyeing processes, and avoiding the dispersion or landfill of potentially hazardous chemicals. This paper presents a textile technique that reuses the colour from waste textiles as the dye for cellulose-based textile screen printing processes. This was developed from the interaction and integration of textile design techniques with materials science processes for cellulose regeneration using a methodology developed by the author. When printed textile finishes reuse the colour from the cellulose source from previous textile lifecycles, no added dyes are needed, and the resulting mono-material textiles are compatible within the context of the circular bioeconomy. The results facilitate a material's future circularity, since the reused dyes do not disrupt the chemical recycling process in the regeneration of colourful, cellulose-based textiles for future product lifetimes.

Introduction

In a circular economy, the transformation of waste textiles into circular materials, as achieved in scientific developments with regenerated cellulose, would restrict design techniques and show limited aesthetic capabilities as opposed to conventional textile processes when working solely with undyed cellulose resulting from chemical recycling technologies. Creating visual and aesthetic qualities with colour in textiles is a key skill attributed to textile designers. To this end, the circular materials practice presented in this paper considers colour in the textile value chain.

Conventional dyestuff for cellulosic materials is oil-based (Ellen MacArthur Foundation, 2017), but its chemical composition is largely unknown (Roos, 2016). Cellulosic fibres are dyed with either reactive, direct or vat dyes (Roos, 2016). Direct dyes do not need a mordant and attach to the fibre through a water bath process where increasing water temperature and salt aids the diffusion of the dye (Ingamells, 1993). Reactive dyes have small pigments that penetrate the fibre with excellent wash fastness since they are water-soluble in a bath with salt and fixed through an alkali (Ingamells, 1993). Vat dyes are not soluble in water and require a, 'strongly alkaline solution of a powerful reducing agent' (Ingamells, 1993, p. 101) to enclose the colour in the fibre, resulting in highly water, light and bleach-resistant textiles. In other words, these dyeing processes for cellulosic fibres require water, chemicals and high processing temperatures. Sulphur and azoic dyes are part of the category of water-insoluble dyes that are suitable for cellulosic fibres. Azoic dyes are categorised as a substance of concern as they have been shown to cause cancer and also because of their long-lasting attachment to the fibre (Ellen MacArthur Foundation, 2017). An additional impact that these dyes cause is created by the large quantity of water used—1kg of cotton requires fifty litres of water (Ingamells, 1993). Dyes can have hazardous impacts on the environment if the textile is landfilled (Ellen MacArthur Foundation, 2017).
The presence of persistent dyes made up of unknown chemicals reportedly impacts on chemical recycling (Elander and Ljungkvist,

2016). Coloured textiles require de-dyeing to remove substances from the cellulose that can hinder the stages of dissolution and regeneration (MISTRA Future Fashion, 2015). Dyes are fixed and can be difficult to remove. The molecular interaction between the dye and the fibre in the dyeing process defines the wash fastness, or in other words, the property of the dye meaning that it does not bleed out during a wash cycle. Most chemical polymer recycling technologies require the removal of the colourant, which is normally achieved by applying high process temperatures, water, and chemicals such as bleach (MISTRA Future Fashion, 2015).

Reusing the colour from the waste source in the new lifecycle of regenerated cellulose fibres is a recent approach for textiles. This is linked to the fact that the closed-loop chemical recycling of cellulose materials is also recent. Projects from Aalto University have demonstrated how colour from the material of the previous lifecycle has been retained for the fibre spinning process, which replaces the act of dyeing the regenerated cellulose once it has become a textile (Kääriäinen & Haarla, 2017). This paper presents the reuse of dyestuff from previous textile lifecycles in textile finishing processes.

Colour in the textile value chain

Designers Thompson and Thompson (2014) state that in the textile value chain, colour can be applied by either stock dyeing fibres, dyeing yarns, piece dyeing rolls of fabric, dyeing finished products or garments, or by printing. They write that “[d]yeing uses the same chemicals as printing [...]; the difference is that dyeing involves immersing the material in dye solution to achieve a solid colour throughout, while printing is used to reproduce multi-coloured patterns and designs on the surface” (Thompson & Thompson, 2014, p. 240). They also state that:

> [P]rinted colour only penetrates the surface of textiles and does not go right through like dyeing, unless printing openwork or sheer fabrics. Printing is used to apply pigment ink. Pigments coat the surface of the raw material, as opposed to chemically bonding to its structure like dyes. Therefore, it is much more straightforward to colour-match with pigments than it is with dyes. The setback is that they are more vulnerable to abrasion and rubbing. (Thompson & Thompson, 2014, p. 242)

Research by the author established how a cellulose dissolution obtained from post-consumer textiles can be screen printed onto cellulose-based textiles for mono-material textile finishes (Ribul, 2023a, 2023b). In the context of the textile value chain, low value regenerated cellulose materials from waste textiles unsuitable for the fibre spinning process can be reused for finishing of cellulose-based textiles made of regenerated cellulose fibres obtained from post-consumer textiles, enabling a closed loop process for chemical recycling (Ribul, 2021). The objective of this research was to introduce colour into textile printing processes that are compatible with chemical recycling technologies for cellulose regeneration.

Circular colour in textile finishes

The technique was developed using a Material-Driven Textile Design methodology developed by the author for textile design practice in materials science research during three research residencies in laboratories exploring chemical recycling of post-consumer textiles into regenerated cellulose: two residencies at RISE Research Institutes of Sweden and one residency at Aalto University (Ribul et al., 2021). The practice work began with a method to produce regenerated cellulose films (Ribul & de la Motte, 2018) and explored colour in the aim to develop new textile processes using regenerated cellulose materials which are inscribed within the circular bioeconomy.

The cellulose dissolution for regeneration in this technique followed a similar method to the preparation for fibre spinning: a cellulose source of postconsumer cotton was dissolved using ionic liquid solvents: 1-Ethyl-3-methylimidazolium acetate (EmimAc) during the residencies at RISE; and Aalto University’s patented Ioncell solvent in the third residency (Michud et al., 2014). The cellulose dissolution was then regenerated using a water or ethanol-based coagulation bath (Ribul et al., 2021).

The practice work built iteratively on a series of experiments for the introduction of colour. Material tests in the first residency established the capability of a regenerated cellulose film to bond with a substrate and subsequent studio practice identified a transfer of colour from other materials such as wood using bioplastics with similar properties. Material experiments in the second residency showed that an un-dyed, post-consumer cellulose source resulted in a transparent regenerated cellulose film that is not very visible on white cellulose-based fabric substrates (such as cotton, viscose and lyocell) for textile finishing techniques such as printing. In this residency, sawdust, synthetic flock, glitter and post-consumer milled cotton were used to enclose physical colour in the form of particles into the films, which however resulted in uneven and undefined colour as opposed to conventional synthetic liquid pigments explored for textiles screen printing in the following studio practice. Prototyping in the third residency then introduced dyed post-consumer cotton, milled with a Wiley mill and dissolved using the method described above for a consistent and even colouration of the cellulose dissolution for textile screen printing. Several processes were tested to achieve a pigmented dissolution that would create a visible print finish in the practice outcomes which are described in the next sections.

Barriers to circular colour

The aim of creating a specific colour range proved more complex than the conventional textile process of blending pigments into water-based binders for screen printing. Several barriers towards the chemical recycling of dyed and finished textiles were identified. These required additional processes to analyse and modify the cellulose source in order to dissolve it.

Turquoise: post-consumer garment

To create a turquoise colour in the cellulose dissolution, the practice work introduced a dyed ten-year-old garment that had been washed several times and had a label stating that the material was made from one hundred percent cotton. Seams, prints and labels were cut out from the garment to avoid non-cellulosic materials (such as synthetic threads, prints and labels) entering the chemical recycling process. The first dissolution experiment did not dissolve the turquoise milled post-consumer cotton. Viscosity tests were performed in collaboration with a materials scientist that showed that the degree of polymerisation could not be measured. This indicated either a high degree of polymerisation where the material has not sufficiently degraded for the dissolution (Palme, 2017), or that there are cross-linking agents present in the dyes or finishes of the textile, disrupting the dissolution process (Smirnova, 2017). Cross-linking agents can bond the dye more strongly into the fabric or create bridges between finishing molecules and fibre molecules (De la Motte, 2012). The dyed fabric was soaked in a chemical solution to remove potential finishes, washed in water and dried in an oven at 40˚C. The chemical treatment did not yield any results when a second dissolution was tested and the cellulose source did not dissolve in a result similar to the first experiment. The dominating factor limiting the dissolution was the potential of unknown chemical cross-linking agents in the finishes of the textile. The analysis, chemical treatment and failed dissolution tests demonstrated that a dyed garment labelled as one hundred percent cotton can contain high levels of unknown substances that disrupt recycling possibilities and require harsh chemicals to remove them.

Cyan, yellow and magenta: ‘100%’ cotton fabrics

Small samples of dyed cotton fabrics in a cyan, magenta and yellow colour range were sourced for their shade and for their one hundred percent cellulose-based content. However, the fabrics could not be milled. Burn and stretch tests evidenced a synthetic content in the plain weave fabric that hindered the milling process, signposting a potential elastane content that showed a slight shine and melted during burning. Therefore, it was not possible to dissolve the textile samples. The experiment highlighted how fabric labelling often does not correspond to the composition of the textile.

Red: recycled cotton textiles

A red dyed, organic recycled cotton fabric could also not be dissolved. Viscosity tests highlighted a high degree of polymerisation in the cellulose chains caused by insufficient degradation of the fabric through wash and wear (Palme, 2017). A sulphuric acid wash degraded the fabric to facilitate the dissolution process. This same process is also recorded in Smirnova’s account of the dissolution of several dyed fabrics (2017). The dye effluent in the sulphuric acid wash can be avoided with a higher degradation of the cellulose source.

Circular colour

The final practice work used three types of pigments in the screen printing process. The colour sources used achieved transparent to opaque prints.

Red: recycled cotton textiles

A sulphuric acid wash to degrade a red cellulose-based recycled cotton fabric led to a significant loss of dye during subsequent washes of the milled cotton. The milled cotton was then dried and a colour change from red to an orange shade pointed to a chemical transformation in the dyes during the dissolution process. The milled, red post-consumer cotton in figure 1 was introduced in subsequent textile techniques in the practice work. Another change in colour took place when the cellulose film on fabric was regenerated in an ethanol coagulation bath. If regenerated in water, the orange colour stayed on the fabric and resulted, however, in brittle films (Figure 2).

Figure 1. Red recycled milled cotton (2018).

Figure 2. Orange cellulose dissolution on fabric (2018).

Black: charcoal

After experiments with dissolving post-consumer dyed cellulose sources failed, possibilities of adding compatible dyes to un-dyed post-consumer cotton cellulose sources were explored by sourcing charcoal. Granulated charcoal is a non-toxic organic material that can be derived from wood ash. The charcoal was added to the post-consumer milled cotton at the cellulose dissolution stage. The dye required no additional chemicals to bond to the cellulose in the dissolution, and resulted in a visible print (Figure 3). At the chemical recycling stage, the wood-based dye can be regenerated with the cellulose material or safely biodegrade.

Figure 3. Charcoal-dyed dissolution on fabric (2018).

Blue: vat dye

A light blue milled post-consumer cotton was dissolved to generate another colour (Figure 4). The light blue shade of the cellulose dissolution was not visible when screen printed onto fabric. A stronger blue shade was obtained when the vat dye corresponding to the dye in the cellulose source was added as a pigment into the dissolution process. The resulting dark blue shade was visible when printed onto fabric and demonstrated that the dissolution can be re-dyed to achieve a stronger colour (Figure 5). Re-dyeing by adding chemicals in the form of pigment is not suitable for a closed loop chemical recycling system. On the other hand, the vat dyeing process did not add a reacting agent normally required for fixing the dye to a fibre.

Figure 4. Light blue milled cotton (2018).

Figure 5. Blue cellulose dissolution on fabric (2018).

Conclusions

This technique reuses the colour from waste textiles as the dye for the cellulose-based dissolution in the textile screen printing process. The dye makes the regenerated cellulose film visible when it is printed as a finish onto cellulose-based fabric substrates. The results also demonstrate several opportunities for dyed mono-material finishes using waste textiles by bonding dyes to the cellulose dissolution without adding chemicals. When the technique reuses the colour from the cellulose source, no added dyes are needed in the finishing process and the resulting mono-material textiles are compatible with the context of the circular bioeconomy. The technique facilitates a material's circularity, since the reused dyes do not disrupt the chemical recycling process of cellulose-based textiles. Therefore, various dyed cellulose dissolution experiments can potentially be combined to match colours while the cellulose is still in its liquid state, similar to the mixing of pigments in conventional screen printing techniques. This could provide more possibilities for blending colour in the finishing process and requires fewer dyed waste cellulose sources to achieve more colours.

Multiple barriers were identified in the chemical dissolution of dyed textiles. A classification could be carried out, distinguishing between the different types of cellulose source dyes that would provide specific colour ranges in textile finishing using regenerated cellulose materials. The classification of dyes could extend in order to consider cross-linking agents that disrupt the chemical recycling process. Abrasion, wash and colour fastness tests could be performed in future research.

The cellulose dissolution for the finishing process however can use low value cellulose waste that is not suitable for fibre regeneration (Ribul, 2021), and results in mono-material cellulose-based textiles designed for future product and material lifecycles. This work can have future implications for research and practice that explore strategies for reuse of materials and products before recycling takes place.

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