Re-using Pre-Consumer Textile Waste and Printing on by Using Smart Pigments

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Abstract:
The increase in demand for clothes and garments has created a substantial amount of textile waste, which affects the environment, economy and society in numerous ways. Objective: The aim of this study has been to develop a new method for re-using the pre-consumer textile waste that is thrown away in the landfill through; defining the problem of pre-consumer textile waste in textile and clothing factories, carrying out a literature review on the re-use and recycling of textile waste and smart pigments for use in textile design through specialist printing techniques. investigating appropriate techniques for the conversion of pre-consumer textile waste into a new form of fabric material and creating a printed design on the new material made of textile waste, using a smart pigment. The study has used printing techniques to apply smart pigments to fabrics made from textile waste. The problems of textile waste and the approaches that have already been taken to reduce it are examined here. The fields of smart textiles and smart pigments are assessed, and the techniques for textile design through printing are evaluated. Results: A new method was developed for developing fabric from textile waste, using a bandaging and stiffening process; this textile material was then printed with printing paste containing smart pigments and the chromic effects were evaluated. This research shows that the techniques and processes employed are effective ways to re-use textile waste for various products with added functionality through the use of smart pigments.

Keywords:
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1. Introduction

1.1 Research Background

The growth in the world's population has led to rising demand for various goods, meaning that an ever-increasing number of factories are constantly being established. Even though these factories are catering to human needs, this creates numerous negative impacts on the environment. For example, polluted water and air from the toxic chemicals used in manufacturing affect the environment and all forms of life around industrial areas. This is a possible underlying reason for the increasing emergence of serious diseases in humans, and it displaces a great deal of wildlife from their habitats and drives them to extinction. Agricultural crops, particularly organic ones, are also affected and becoming sparse.

According to Sule & Bdhan (2001), prodigious demand from the garment industries has produced a scarcity of natural fibres. This means that there is a need to find an alternative approach to solving this problem. For instance, China is the leader in the production of mass-produced, cheap and fashionable apparel in the world, and this means that the majority of brands cooperate with their suppliers to reduce costs. However, China now has pressing environmental issues which were created by the waste generated by the apparel and textile industry.

According to a recent report by the World Bank (2012), there is some evidence that the environmental violations related to solid and liquid waste from an enormous number of textile companies need to be improved. One of the accounts described illegal actions such as the discharge of water waste from a textile dyeing and printing factory into a secret pipeline draining into a river, rather than treating or burning the polluted waste. After this infraction, the government divided factories into "red" and "black" categories, giving each factory a certificate so that multinational apparel retailers could identify those factories presenting a risk to the environment. However, these policies were not followed by some suppliers, their retailers and the brands, in order to avoid the extra costs involved.

Furthermore, there is a substantial amount of textile waste at each stage of garment production. McConnell (2011) reported that 67% of textile waste from factories was disposed of in landfills,

with only 30% of this being recycled, and less than 10% sold to other retailers. A significant number of textile factories discharge their waste into landfills, with much of the waste being disposed of by burning or burying. This creates serious harm to the environment, affecting both the ecosystem and human life. Damage to natural habits is reflected in the increase in global warming and climate change, causing drought and flooding; it also affects the economy and the quality of essential services.

It is almost certain that the production of more waste without recycling will create poor conditions for life, both in the present and the future. There are numerous countries and organisations that are concerned with preventing and mitigating the environmental issues created by factories, either in their native land or their suppliers' country. Moreover, the importance of re-using and recycling textile waste and finding safe methods to treat, produce and dispose of textiles is paramount. For example, legal regulations were designed in Europe to create a formal legal status for the analysis of the textiles and chemicals in the fibres which affect the environment. A recent paper published by the Retail Forum for Sustainability (2013) reveals that the EU regulations forced factories to reduce the effects of hazardous toxic and chemical components within the garment and textile industries; this constituted a positive step towards improving customers' habits, encouraging them to re-use and recycle waste garments, and towards finding sustainable products that are easy to re-use. Recent research has suggested that the redesign of garments and jeans is an effective method of improving their ability to be recycled, and that this would help to reduce the volume of waste (Bommel and Goorhuis, 2014).

According to Balgoois' lecture entitled 'Design for Disassembly', instead of a garment reaching the end-of-life stage, the choice of a different design method can be made to make the garment reusable. This approach to design would be able to regulate the amount of textile waste being disposed from it. The existing features of the products should also be considered, such as being versatile, washable and long-lasting. Furthermore, although eco-friendly textile materials do exist, their status as 'eco-friendly' depends on how they are used. In addition, the manufacturers of textiles and apparel that use different materials can help in the search for ways of recycling them that can be planned in advance (Balgooi, 2015). For example, the construction of a bag out of polyester with metal edges and a leather holder can be made more durable and washable. Each part of the bag can be re-used in one of two ways: either it is already a sustainable product, or it can be reused in another production operation. There are no limitations on the design of textile-based products for disassembly if they also have a functional layout.

1.2 Aims and Objectives of the Project

The re-use and recycling of textile waste can bring great benefits from various points of view. From an environmental perspective, the shortage of natural fibres will be alleviated, and the pollution which is created by textile and clothing factories during the manufacturing process or the production of non-natural fibres which affect the water, air, and forests will be curbed. From another standpoint, it will reduce the cost of the transfer of waste, and will create new products made of the waste with a lower cost than the original, in addition to supporting the sustainability that is encouraged by the most developed countries. The overall aim of the current project is to investigate a new method for re-using this textile waste in the design and manufacture of textile-based materials and products with added smart functions. The specific objectives of the research are listed below.

- To define the problem of pre-consumer textile waste in textile and clothing factories.
- To carry out a literature review on the re-use and recycling of textile waste and smart pigments for use in textile design through specialist printing techniques.
- To investigate appropriate techniques for the conversion of pre-consumer textile waste into a new form of fabric material.
- To create a printed design on the new material made of textile waste, using a smart pigment.

2. Literature Review

2.1 Recycling Textile Waste

In view of the large amount of waste created by the clothing and textile industries, regulations and rules have been imposed by governments to reduce this waste and the associated environmental issues. Many individual projects have described the re-use of the waste textiles and garments in manufacturing new products such as accessories and interior textiles. Moreover, many companies have tried to find solutions to these problems and to generate commercial profit. For example, in Pakistan, an attempt has been made to support the economy and reduce unemployment by managing textile waste produced from textile factories. The amount of solid textile waste is 794,209 kg per day, generated from various textile-related items. This waste is sold, and the

cotton waste alone is valued at around $125,027 per day.

Rather than sending pre-consumer waste from textile and other items to the landfill, cotton waste is sold for use as an alternative fuel that is cheaper than wood or coal. Moreover, cutting rags are recycled and converted into new products such as ropes and fillings of shredded textiles (Norman et. al. 2013).

Textile waste can also be used in the construction of buildings as insulation. Briga et al. (2012) developed this ingenious solution for the building industry from the re-use of waste woven textiles made of cotton, wool, linen, silk and acrylic. Moreover, they showed that textile waste can create an alternative thermal insulation for buildings by creating a double wall with the new material made from textile waste. The results of this study demonstrated that the new material is relatively eco-efficient and sustainable, is an effective solution for reducing energy consumption, and offers great benefits for the environment.

In addition, eco-fashion and eco-textile-related topics have become very fashionable, and the recycling of garments and textiles has attracted much attention. Logan (2014) holds the view that clothes can be remade and recycled to become new products with an infinite life expectancy. For instance, denim and jeans made of cotton are popular products worldwide, but create a great deal of pollution from their waste. Many researchers have tried to find ways to use these waste products. Improvements have been made by recovering and recycling denim waste from the mill into nonwoven felts for vehicles and building insulation. The wasted denim and jeans have also been disassembled into their component cotton fibres and mixed with unused cotton to produce new yarns, fabrics, and garments (Paul, 2015).

2.2 Smart Textiles and Chromic Pigments

Significant scientific and technological advances affect all aspects of life and commerce. One of these advances has taken place in the textile and garment industry and is intended to create economic benefits and a healthy environment for human beings. Through research and experimentation, smart textiles have been found, and the barriers and problems that had been faced have been overcome to create a new, more efficient invention that can improve lifestyles and adapt to the environment (Schwarz et al., 2010).

According to Cherenack and Van Pitereson (2012), a smart textile can be defined as an intelligent fabric or e-textile that has functional features, is wearable and meets customers' needs, such as monitoring for a medical purpose or sports activities. A further definition of smart textiles, given by Van Langenhove and Carla (2004), is that these textiles "can sense stimuli from the environment, to react to them and adapt to them by integration of functions in textile structure. The stimulus and response can have an electrical, thermal, chemical or magnetic". The new chromic textiles are an example of this.

There are numerous types of smart textile, created using various techniques including finishing processes or the addition of electronic objects (Schwarz et. al., 2010). From a designer's perspective, a smart textile can be created through a finishing process in the textile's production, using certain chemicals to add smart features to the textile, such as a change in colour when the environment changes, for example, the temperature, or exposure to UV light.

This allows novel textile design through the use of chromic pigments, which are able to respond when there is change in temperature or UV light. Thermochromic pigments are affected by temperature change. Chowdhury et al. (2012) reported that thermochromic pigments were able to change colour in response to very small changes in temperature. These chromic pigments can be used in innovative fashion and textile design. Recent research has suggested that more investigation and experimentation is needed in using thermochromic dye in textile design, since very few studies have been done in this area. To this end, functional home textiles have been designed, which change their colour and patterns using a thermochromic pigment integrated with electrically conductive yarns and new technology. The yarns are added into the textile structure to create a heat-stimulated fabric. Moreover, by using a printing screen, various different designs of thermochromic pigment can be applied. To produce heat-sensitivity in the textile, a digital multi-meter is used to control the power supply and select the time limit for changing colour (Chen and Huang, 2015).

Photochromic pigments are affected by sunlight. According to Vikova and Vik (2015), photochromic pigments are applied to a sample of a smart textile, which is then used as a UV sensor that changes colour in response to light. This property can be used in "protective ophthalmic lenses, and could be potentially used in security printing, optical memory and switching, solar energy storage, nonlinear optics and biological systems, cosmetics, and electrophoretic displays" (Peng et al. 2015).

2.3 Textile Design through Printing

Textile printing is a technique which can be used to create patterns on the surface of textiles. There are four main types of traditional printing techniques; direct printing, discharge printing, resist colouring, and devoré printing. The procedures in the printing process include the development of the print paste, the printing of fabric, drying, dye and pigment fixation through high temperature steam or dry heat, and the washing-off stage (Edward, 2008).

Ink jet printing can also be used to print on and create a design for the fabric. Although these innovations are aimed for the most part towards fashion applications, they may help in the positioning of important practical components. This type of technology has produced a new kind of Textile Digital Craft, a term coined by Oxman (2007) for "a design method which promotes the creation of novel structural systems through processes of digital fabrication and assembly".

Through the use of mechanised printing, Textile Digital Craft has reached a stage of development that is able to conduct both fabrication and assembly, and can be used to make design decisions, since the mechanised printing can faithfully duplicate the model pattern. Textile patterns can be generated and fabricated using computerised techniques, and then transferred to the appropriate stage for prototyping (Chapman and Little, 2012).

3. Research Methodology

3.1 Materials and Preparation

Many different fabric samples were collected for the experiments; some were bought from a waste fabric store in Edinburgh, some were obtained from a Schofield Finishers in Galashiels as waste textiles, and the rest were fabric waste from the sewing workshop at the School of Textiles and Design, Heriot-Watt University.

3.2 New fabric development techniques

In order to develop a new material from pre-consumer fabric waste, it was necessary to collect the waste and test various methods to find the most suitable one. This project involves how to reuse recycled textile waste and several possible techniques could have been used that have already been developed and tested, such as weaving or stitching textile waste to create new types of fabrics for various product designs and development.

In addition to the techniques mentioned above, a new technique was developed for this project, to create new textile materials which could be used for many different products. This technique was made through bandaging and stiffening the textile waste to create a single flat piece; this can be recycled and reused many times to create various items. The textile pieces were prepared on a flat surface in a matted state, without any particular arrangement. A stiffening paste was then made using 6 table spoons of corn-starch, 50 g of Waite glue (non-toxic) and 0.5 l of water. The so made paste was brushed on to fabric waste to stick them together. After being dried, the newly made fabric piece was ironed to remove any dents or imperfections.

It is also possible to arrange the pieces to form patterns before applying the stiffener. Patterns and designs can also be printed on the new material using pigments and a printing screen.

Smart pigments were used in this project, including thermochromic and photochromic pigments. The pigments were applied to many different newly developed fabric samples from fabric waste through printing, in order to determine the best results of this colour application process. Table 3-1 shows the smart pigment that used.

Table 3-1 Smart pigments used

Type of colour	Incentive	Fixed time
Thermochromic-blue	22 ºC	50 ºC
Thermochromic-red	22 ºC	50 ºC
Thermochromic-black	31 ºC	55 ºC
Thermochromic-pink	31 ºC	55 ºC
Thermochromic-green	33 ºC	55 ºC
Thermochromic-yellow	31 ºC	55 ºC
Photochromic-red	Direct sunlight	50 ºC
Photochromic-blue	Direct sunlight	50 ºC
Photochromic-orange	Direct sunlight	50 ºC

The printing paste was made using 1 g of thermochromic or photochromic pigment, 10 ml of acetone and 100 g of binder. Figure 3.1 shows the first try to applied smart pigment on remain fabrics.

Printing on the new material using a printing screen with the true design and colours made the pieces more attractive. A small patterned screen print design was used to showcase the effect of the smart pigment as in Figure 3.2.

The final stage of the project is to engineer design products from the new material made of textile

waste. Due to the limited time available, small product samples were prepared to test the product. The list below is the items that were made of textile waste.

1. Block-out shutter.
   Two types of shutter can be created from the textile waste:
   A. Rolling shutter.
   B. Sliding shutter.
2. Smartphone covers.
3. Designs on the new material.
4. Covers for some stationery items.

Figure 3.1 applying smart pigment

Figure 3.2 using the printing screen

4. Results and Discussion

4.1 products made of per-consumer textile waste

Various results were obtained from reusing textile waste by using this new bandaging and stiffening technique, and these were determined by the type of textile, as shown in Table 4-1. The different types are shown in Figures 4.1 and 4.2

Table 4-1: Results from different fabric types

Type of fabric	Layers	Flexibility	Texture
Thick fabrics made of wool.	Difficult to apply	Tough	Rough
Thin fabrics made of cotton.	Moderately easy to apply	Flexible	Soft

Figure 4.1 the thin fabric waste

Figure 4.2 the thick fabric waste

4.2 New Products Made Using Chromic Pigments

The new method was applied to thin fabrics, using the ability of this material to accept printing by smart pigment in order to make the new products that are described below.

4.2.1 Block-out shutter

Two types of shutters have been created from the textile waste, and the application of chromic pigments can add a stylish appearance and functional features to the shutters.

A. The rolling shutter underwent an application of thermochromic pigment, which changes colour depending on the change in temperature. The colour change is reversible. The sample shutter made of textile waste was made similar to a real shutter, then was printed by printing paste containing thermochromic pigment.

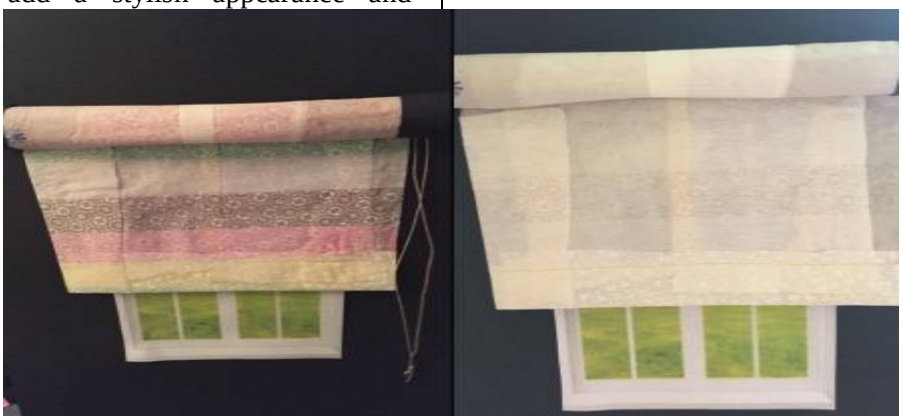

Figure 4.3 shows the effect of colour change reacting to heat.

Figure 4.3 the rolling shutter before (left) and after (right) exposure to heat

B. The sliding shutter underwent an application of photochromic pigment, which changes with the level of sunlight. The pieces were cut and made of textile waste, and printed using printing paste containing photochromic pigment. Figure 4.4 shows the sunlight effect, the colour appeared when the shutter was exposed in comparison to the unexposed shutter.

Figure 4.4 the sliding shutter before (light) and after (right) exposure to sunlight

4.2.2 Smart Phone Covers

The smart phone covers underwent an application of thermochromic pigment. The (Red, green and black) colour at room temperature will disappear when the phone becomes hot due to overuse. Both covers were made of fabrics from textile waste. This can be used to indicate overuse to mobile phone users This can reduce the negative impact from over using such devices such as multiple tasks and distracting focus and others risks. Figure 4.5 and 4.6 show the colour effect affected by heat of the covers.

Figure 4.5 the smart phone cover before (right) and after (left) exposure to the heat

Figure 4.6 the smart phone cover before (right) and after (left) exposure to the heat

4.2.3 Innovative Fabric Design

The designs on the new fabric made from fabric waste were created using thermochromic pigment, partly using a drawing technique with a normal fabric pigment and a drawing technique with a thermochromic pigment that will change with a suitable incentive. Figure 4.7 shows the difference before and after applying heat to the design and the red coloured dress, hat and the umbrella. The green inside the umbrella and the yellow flowers on the green branch disappeared with the application of heat.

Figure 4.7 the drawing design before (right) and after (left) exposure to heat

4.2.4 Various stationery covers

Various types of stationery covers have been produced from fabrics made from textile waste. Producing this type of item from waste natural sources can reduce the cost of covers and the products can be made more attractive through a printing process using printing paste containing smart pigments. Figure 4.8 shows an envelope made of textile waste and printed by thermochromic pigment.

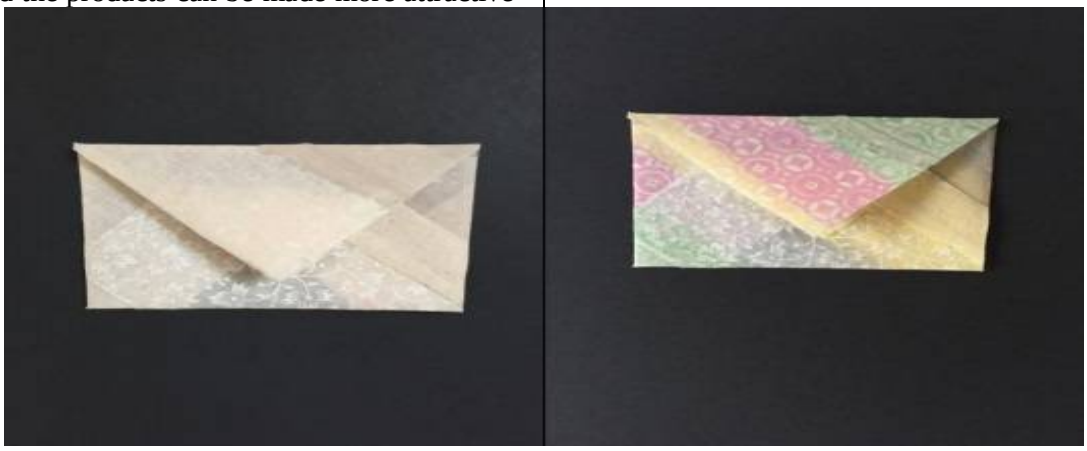

Figure 4.8 the envelope before (right) and after (left) exposure to heat

5. Conclusions, Limitations and Recommendations for Future Work

5.1 Conclusions

The objectives of this project were framed after an exploration of the previous research, and through experimentation and creating new products, and they were successfully achieved.

- The problem of pre-consumer textile waste in textile and clothing factories has been defined.

It has been evaluated through the literature review of this research that a large amount of textile waste is produced by the garment and textile industries. This has severe impacts on the environment worldwide. In addition, although many countries have made efforts to impose regulations and penalties to curb these problems they have not been effective. Therefore, it has been defined as exploring effective techniques and methods to design and manufacture textile products by reusing textile waste.

- A literature review of the re-use and recycling of textile waste and smart pigments for use in textile design through specialist printing techniques has been performed.

The attempts of developing countries to find a way to reduce the cost of manufacturing and decrease unemployment were described. Furthermore, recycling textile waste can reduce unfavourable effects on the environment. This study can therefore offer one of many solutions to these problems. However, each stage of this project to develop a new material from textile waste was a manual process, and it would therefore be time-consuming to produce a significant amount of recycled fabric using this method. It will consequently be difficult to use this technique in factories that rely on using thick textiles in their production. However, these results can be applied within many other areas of the garment and textile field. In addition, smart functions can be added to the recycled textile waste using this method, which may suggest many directions for further research. Numerous researchers have studied the various types of smart pigments, and the field of smart pigment application; however, to date no research has been conducted on the use of smart pigments on textile materials made from textile waste.

- Appropriate techniques for the conversion of pre-consumer textile waste into a new form of fabric have been investigated.
- Various textile products made from textile waste have been designed and hand-made. The designs were printed onto the newly developed textile materials using chromic pigments.

According to the experiments and preparatory work undertaken as part of this project, pre-consumer textile waste has been recycled using methods such as stitching and weaving, which were already in commercial use. However, the new technique employed uses bandaging of the textile waste and then the application of a stiffener to achieve acceptable results. In addition, the newly developed fabrics made from textile waste are sustainable textile materials that can be recycled in many different ways. Smart pigments have been applied to the newly developed material and the designs were printed through a screen-printing technique using printing paste containing chromic pigments.

5.2 Future Research Recommendations

There is a shortage of previous research in the area

of textile design using smart pigments, and further work in this field is required. The new trend is to use technologies and new methodologies to improve human life. For example, trying to find wearable technology and intelligent textiles. According to Mattila (2014), applying chromic and conductive materials to garment design could have uses in the medical and healthcare field. This was found a few years ago by Adidas when they created a smart T-shirt that worked as a heartrate monitor for runners (Textronics, 2010). In addition, there is an attempt to find a textile can change shape or colour under stress, which can be used to design a garment that can carry all kind of electronic devices and cover costumers' needs (Davis et al., 2009). Therefore, further research is needed to improve and develop this technique; the use of machines would decrease the time required to create one piece of this fabric made of textile waste and find other ways to use it. In addition, further development of the type of products created as part of this project using smart pigments will create a new revolution in the fields of health care, garments, and fashion, and integrate this with developing technologies and electrically conductive materials.

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