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Reverse engineering of wool fibre into its constituent components as functional additives to form wool based structures

Barnaby Caven^{a*} and Thomas Bechtold^a

Research Institute for Textile Chemistry and Textile Physics, University of Innsbruck, Hoehsterstrasse 73, Dornbirn, Austria, A-6850

Abstract

The complex hierarchical structure of the wool fibre, both in terms of chemical and physical morphology, offer various components with differing, yet desirable properties. This study showed how the wool fibre can be systematically reverse engineered into its constituent components, with minimal to no chemical or physical change to the desired component. Through a combination of targeted chemical and mechanical attack, the cuticle scales were separated from the cortex. The cortex was then broken down into the cortical cells, through mechanical agitation. Moreover, the breakdown of the cortical cells can be achieved through an enzymatic action, producing macrofibrils. The subcomponents were then utilised to form wool-keratin structures, using a keratin extract as the matrix. Control of the placement of the components can alter the properties of the final product.

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1. Introduction

Wool fibres are one of nature's most advanced composite structures. Comprising of both amorphous and crystalline regions, in conjunction with the hierarchical structure, makes the wool fibre very complex. The complexity of the physical and chemical composition of wool has been well documented [1,7]. A significant point to

* Corresponding author. Tel.: +43 5572 28533 593

E-mail address: Barnaby.caven@uibk.ac.at

note is that each component of wool has specific physical and chemical composition and therefore a unique role to play in the wool system. The cuticle scales that surround the cortex, are rich in cystine, an amino acid containing Sulphur, it's the disulphide bond that gives wool its chemical and mechanical stability. Whereas the cuticle scales are hydrophobic, the cortex is actually hygroscopic, wool fibres can absorb 30 % by weight of moisture from the atmosphere. This combination of properties provides a unique surface of the wool fibre, which were investigated. As the individual components of the wool fibre possess desirable properties, such as; chemical resistance and high moisture absorbency, reverse engineering of the wool fibre into its major sub components, with altering the physical or chemical structure, allows for the desired properties to be controlled and implemented onto passive substrates. This study will investigate each component of wool fibre, and its addition to a structure that doesn't possess the added function of the wool component. Moreover, as well as looking at the addition of wool components to other substrates the investigation looks into the formation of wool-keratin composite structures.

2. Materials and Methodology

The merino wool was sourced in sliver form from Schoeller GmbH & CoKg, Hard Austria, the slivers had been scoured and carded. The fibre diameter, determined through light microscopy, $18 \mu\text{m} \pm 3 \mu\text{m}$. The wool fibre was washed in an alkali solution, then air-dried and stored in a desiccator, prior to all experimental work.

2.1. Isolation of cuticle scales and cortical cells

The removal of the cuticle scales from merino wool fibre, with no damage to the cortex has been previously shown [8]. In summary, 1 g of wool was refluxed in 100 ml of analytical grade formic acid (Carl Roth GmbH + CoKG) at $100.07 \text{ }^\circ\text{C}$ for 17 mins. Where upon the fibres were transferred to fresh formic acid, at room temperature, and agitated in a laboratory shaker for 16 hours. The cuticle stripped fibres were extracted from the formic acid, then neutralised, and washed in deionised water. The resultant solutions from both the reflux and shaking stage were filtered, using a PTFE filter pore size $0.45 \mu\text{m}$, leaving behind the cuticle scales, that were then washed. The cortex only fibres were subjected to further formic acid attack. Submersing the fibres in 100 ml of fresh formic acid in an ultrasonic bath at $35 \text{ }^\circ\text{C}$ for 20 mins, degraded the fibres sufficiently to breakdown the cortex into cortical cells.

2.2. Extraction of keratin from waste wool

Several methods for the extraction of keratin from various sources have been developed [9,12], each method sites the disulphide bond as the crucial bond that requires breaking in order for dissolution of the fibre to occur. Initial work on the determination of the protein structure of wool employed Thioglycolic acid (TGA) to reduce the disulphide bond [13]. No preferred method has been reached as of yet as yields are relatively low, $<35 \text{ \%w/t}$, and the duration of the experimental procedure can vary from 16 hours to several days. Complex solutions that are unsuitable for anything other than laboratory scale work are commonplace.

A combination of three well defined extraction methods was used [9], [13], [14]. 5 g of wool was reduced in a 500 ml solution containing, 0.2M TGA, 0.1M Na_2HPO_4 , for 18 hours. After the reduction was complete, the wool was removed and rinsed with a 0.1M Na_2HPO_4 solution. Where after the reduced wool was digested through enzymatic action, where 1g of cuticle removed wool was submersed in a solution containing 0.1 g trypsin, 100 ml of 0.1M Na_2HPO_4 for 1 hour at pH 8. The digestion was stopped through the addition of trypsin inhibitor from the pancreas of a bovine, T0256. The solution was then centrifuged at 5,000 g for 15 mins, where the undigested components were discarded. The supernatant was then adjusted to pH 4.8, with 0.1M HCL, where precipitation occurred. Separation was achieved again through centrifugal force, 1,000 g for 10 mins.

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