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The effects of ultrasonic agitation in laundering on the properties of wool fabrics

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ABSTRACT

This paper investigates the use of ultrasonic agitation as a method for reducing felting and area shrinkage during the laundering of wool fabric. Work was conducted to evaluate the changes in fibre and fabric properties after repeated exposure to ultrasonic agitation, and also the effectiveness of ultrasonic treatment to remove common stains. Fabric colour, appearance, tensile strength, dimensional stability and thickness were measured before and after each test. Ultrasonic agitation produced fine cracks in the scale structure of the fibre, but these had negligible effects on the strength and colour when compared to hand washing. Ultrasonic agitation caused less fibre migration than hand washing, with a reduced rate of thickness increase and felting. Ultrasonic agitation increased the level of stain removed from the fabric when compared with hand washing.

1. Introduction

Wool is cleaned in many different ways throughout its manufacturing and retail life cycle. Irreversible entanglement of the fibre, better known as felting, is the largest factor impacting the quality, processability and appearance of a wool product after it has been washed [1]. Wool felting during scouring reduces processing yields and mean length of processed fibres due to increased fibre breakage [2]. Felting during laundering causes dimensional shrinkage that affects the garment appearance and size.

The mechanism of fibre felting is very complicated and findings from the literature are not always consistent. Felting is a form of tangling produced by the persistent migration of individual fibres in the tip-to-root direction, which is caused by the directional frictional effect (DFE) of fibres [3–5]. Interlocking of the scale structure, during migration, is an irreversible process. Fibre migration is increased significantly when the wool is placed in a warm, moist, lubricated environment in the presence of mechanical agitation [6]. These conditions are the same as those found in most wool cleaning systems, with the detergent acting as the lubricant. Felting can be reduced if the mechanical agitation is reduced. However, liquid transfer through the fabric is also lowered, causing less efficient cleaning. Ultrasonic agitation could be used to provide the liquor/fibre movement as it works on a micro scale and limits fibre migration.

Ultrasonic agitation is an effective cleaning method for the removal of grease and surface contaminants. Ultrasonic agitation is generated by using high frequency sound waves (over 16 kHz) with the frequencies of 20–120 kHz often used for cleaning purposes [7]. Frequency sweep is often used as it avoids damage to delicate parts and to reduce the effects of standing waves within the cleaning bath [8].

Ultrasonic cleaning works because ultrasonic sound waves radiate into a solution in the form of a vertical wave. Negative acoustic pressure causes the fluid to fracture generating vapour filled "cavitation bubbles" of about 10–100 μm in diameter (20 kHz) [9]. The negative acoustic pressure cycles cause bubble growth and the positive acoustic pressure cycle causes the bubbles to rapidly collapse. The bubble undergoes a violent implosion, generating fluid jets and shock waves [10,11]. The micro-agitation occurring in the vicinity of the cavitation bubble effectively wets out the surface and helps to displace particulate contaminants or grease.

Ultrasonic agitation is not new to the textile industry [12,13], with initial investigations dating back to 1954. As new technologies are required to reduce the cost and environmental impact of textile processing, researchers have again looked at the use of ultrasonic agitation to provide unique mass transfer [14] within the processing liquor or provide the energy to undertake sonochemistry [10,15]. Recent investigations include dyeing [16,17], bleaching[18], bast fibre degumming [19–21] and enzyme desizing [22]. There has been some interest in ultrasonic cleaning of different fabrics [23,24], but little has been reported on how ultrasonics affects the properties of wool fabrics.

Earlier work in the scouring of greasy wool fibre [25] led to the observation of modification to the structure of the wool fibre during ultrasonic agitation. The surface of the wool fibre was disrupted with micro-cracking evident in the scales. The work also

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showed that the use of ultrasonic agitation improves the grease and dirt removal from wool fibres during scouring.

This paper extends the earlier work to investigate the use of ultrasonic agitation to reduce the level of felting in wool fabrics during laundering while maintaining the cleaning efficiency and fabric properties.

2. Materials and methods

2.1. Fabric preparation and testing

Griege fabric samples (200 mm warp, full fabric width weft) were scoured in a solution of 1.0 g/l Solpon 2448 (Boehme) and 0.5 g/l of sodium carbonate (Sigma Aldrich) at 60 °C for 20 min using a liquor ratio of 10:1. The fabrics were then padded to a liquor content of approximately 80% before being rinsed in warm water twice, with padding after each rinse. After the final padding they were dried at 105 °C for 1 h before being conditioned to 20 °C/65% RH (AS2001.1 1995).

After conditioning the test fabrics were measured for dimensional size, colour, thickness, tensile properties and visual appearance. The fabrics were marked up for assessment of dimensional stability by sewing a thread into each corner of two, 150 mm × 150 mm squares centred on the right hand end of the fabric. Each side of each square was measured for length and the results recorded. The marking system and pattern for measuring each square has been given in Fig. 1. Fabrics were measured for colour using a Datacolor SF600 spectrophotometer. Measurements were taken using a LAV aperture with instrument averaging. Four measurement cycles with five spectral captures per cycle (UV included) were conducted for each sample.

Fabric thickness was measured using a Mesdan LAB digital thickness tester at a shoe pressure of 0.5 kPa. Each fabric was measured 10 times and the mean value calculated. Tensile property measurements were conducted according to AS2001.2.3.1 using a Lloyd LR30K tensile tester. A gauge length of 100 mm and test width of 50 mm were used. A rate of extension of 100 mm/min was used for all tests. Ten tensile samples were tested for each fabric laundering system.

All of the ultrasonic treatments were carried out in a Deacon FS300B Ultrasonic bath at a liquor ratio of 100:1. The bath working frequency was 35–45 kHz (sweeping). All experiments were carried out at 60 °C. All error bars in this report are set at 1 standard deviation from the mean value.

2.2. Dimensional stability experiments

The dimensional stability experiments involved repeated wash/dry cycles using ultrasonic agitation in comparison with a hand agitation. The two samples (hand and ultrasonic agitation) were run in tandem through a series of ten, 60 min wash and dry cycles.

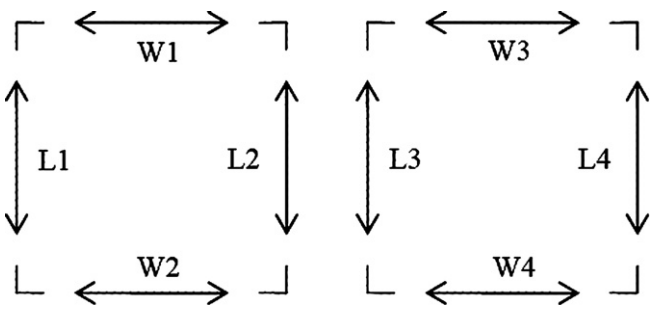

Fig. 1. Marking and measuring pattern for fabric dimensional stability.

The liquor used contained 0.5 g/l Hydrapol TN450 (Nonyl Phenol Ethoxylate detergent, Huntsman Chemicals) and 0.2 g/l sodium carbonate. Colour and dimensional change measurements were taken after every wash. Appearance and fabric thickness were taken after every second wash. Tensile properties were measured at the completion of the tenth wash/dry cycle.

After each of the treatments, fabric was hand rinsed 3 times in 50 °C water. After rinsing, each of the samples was padded to 80% liquor content to remove excess water before oven drying at 105 °C for 1 h. The fabric samples were then conditioned and measured for dimensional size, colour, thickness, tensile properties and visual appearance using the methods described above. Mean percentage width, length and area dimensional changes were calculated according to Eqs. (1), (2) and (3), respectively.

$$\Delta W\% = \left[\frac{(W1_b - W1_a)}{W1_b} + \frac{(W2_b - W2_a)}{W2_b} + \frac{(W3_b - W3_a)}{W3_b} + \frac{(W4_b - W4_a)}{W4_b} \Big/ 4\right] \times \frac{100}{1} \quad (1)$$

where $\Delta W\%$ is the percentage width dimensional change, b denotes dimension measurements taken before treatment, a denotes dimension measurements taken after treatment and $W1$, $W2$, $W3$ and $W4$ are described in Fig. 1.

$$\Delta L\% = \left[\frac{(L1_b - L1_a)}{L1_b} + \frac{(L2_b - L2_a)}{L2_b} + \frac{(L3_b - L3_a)}{L3_b} + \frac{(L4_b - L4_a)}{L4_b} \Big/ .4\right] \times \frac{100}{1} \quad (2)$$

where $\Delta L\%$ is the percentage length dimensional change and $L1$, $L2$, $L3$ and $L4$ are described in Fig. 1.

$$\Delta A\% = \Delta L\% + \Delta W\% - \left(\frac{\Delta L\% \times \Delta W\%}{100}\right) \quad (3)$$

where $\Delta A\%$ is the percentage area dimensional change.

2.3. Analysis of fibre cracking

Analysis of fibre cracking involved isothermal dyeing trials on two of the laundered fabrics. One fabric was subjected to 1 h of treatment with ultrasonic agitation in 0.5 g/l Hydropol TN450 and 0.2 g/l sodium carbonate, whereas the other fabric was subjected to the same wash liquor with no agitation. After washing, fabric samples of 1.4 g were isothermally dyed at 40 °C in 100 ml of distilled water with 0.2% w/w Lanaset Blue 2RA (Ciba Specialty Chemicals) in an Ahiba Nuance Top Speed laboratory dyeing machine. The pH of all dyeing samples was 6.85 at the start of the dyeing. Samples were removed every 25 min and measured for colour depth. Colour depth was evaluated in terms of K/S values and these were calculated using Kubelka–Munk's equation ($K/S = (1 - R)^2/2R$, where R is the reflectance). The reflectance values were measured with a Datacolor SF600 spectrophotometer using the standard illuminant D65 (LAV/Spec. Incl., D65/10°).

The fibre surface before each of the isothermal dyeings was examined using a LEO1530 field emission gun scanning electron microscope (SEM). Measurements were conducted with an EHT of 5 kV, working distance (WD) of 15 cm and aperture size of 60 μm.

2.4. Stain removal experiments

The effectiveness of ultrasonic agitation in the removal of five common stains was investigated. The stains used were coffee, tea, red wine, engine oil and orange soft drink. A piece of the test fabric was thoroughly wet out in a bath of the stain over a 24 h per-