Soil Removal from Polyester Fabric by Laundering with Frequency-modulated Ultrasound

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Abstract: The effectiveness of ultrasound in washing textiles was investigated using polyester woven fabrics soiled with model contaminants such as oleic acid/Sudan III mixture and carbon black. The soiled and original fabrics were washed together in aqueous solutions with shaking or frequency-modulated ultrasound. The detergency and the soil redeposition were evaluated from the change in the surface reflectance of the soiled and the original fabrics due to the washing. The results were strongly dependent on the type of mechanical action. Ultrasound removed the contaminants in a short time and at low bath ratios as compared with shaking. In addition, the ultrasound caused little damage to the fabric during washing. The detergency was much larger for the ultrasonic washing than for shake washing in aqueous solutions containing alkali, surfactants, and commercial detergent. However, uneven cleaning and soil redeposition were frequently observed during ultrasonic washing. This was the only observed limitation to this approach of textile washing.

Key words: detergency, soil redeposition, ultrasonic wave, artificially soiled fabric

1 INTRODUCTION

Textiles are washed in liquid media such as water and organic solvents. Water has high solvency for many substances as well as demonstrated environmental and occupational safety. However, hydrophobic contaminants are difficult to remove in water, especially from hydrophobic surfaces such as polyester. Aqueous detergents may also damage textiles. Fabric care by domestic laundry is commonly performed using automatic washing machines such as the top- and front-loading machines, V-axis clothes washers, or H-axis clothes washers. The aggressive agitator actions, and flowing and rotation can damage delicate fabrics during laundering. Ultrasound has been utilized mainly for hard surface cleaning and is another type of mechanical action for soil removal. Ultrasonic cleaning depends on cavitation, i.e., the rapid formation and violent collapse of bubbles or cavities in cleaning liquids. Recently, ultrasonic energy has been applied to textile processes in the fields of bleaching, dyeing, enzymatic desizing, laundry, and drycleaning. Compared to conventional mechanical action, the use of ultrasound without mechanically agitating the wash bath is a very gentle approach to cleaning textiles, in spite of the strong mechanical action generally needed for soil removal. In addition, the ultrasound removes the soils deposited on the fabric at a low bath ratio and in a short time. This can lead to water and energy-saving cleaning systems for textiles.

In the present study, textile washing via ultrasound was performed using frequency-modulated ultrasonic equipment that generated a uniform ultrasound field inside a tank. Polyester fabrics both unsoiled and soiled with model oily or particulate contaminants were used. The soiled and unsoiled fabrics were washed together in aqueous solutions with shaking or ultrasound. Soil redeposition and detergency were determined from the changes in the surface reflectance of the fabrics after washing. By comparing this approach to that involving only shaking, we clarified the advantages of ultrasonic cleaning in terms of bath ratio, wash time, fabric damage, and detergency performance.

2 EXPERIMENTAL PROCEDURES

2.1 Materials

Artificially soiled fabrics were prepared from plain-woven polyester fabric composed of textured yarns (Toray Tropical) from Shikisensha Co. Ltd. The fabric was purified twice in boiled water and then cut into swatches 50 mm × 50 mm (0.3 g). A mechanical action (MA) test piece with 5 holes (Danish Textile Institute) was used to evaluate fabric
damage due to washing.

Oleic acid and Sudan III (oil-soluble dye, CI 26100) were selected as the model oily soils. Carbon black (SEAST SP, Tokai Carbon Co. Ltd.) was used as the model particulate soil. For preparing detergent solutions, we used sodium dodecyl sulfate (AS, Wako Pure Chemical Industries, Ltd.) and polyoxyethylene (9) dodecyl ether (AE, BL-9EX, Nikko Chemicals, Co., Ltd.) as surfactants. Critical micelle concentrations of AS and AE in the presence of 1 mmol/dm$^3$ sodium chloride were determined to be 7.1 mmol/dm$^3$ and 0.20 mmol/dm$^3$, respectively, from the surface tension obtained by the pendant drop technique. Commercial alkaline detergent powder containing linear alkylbenzene sulphonate (LAS) and AE was used. Sodium hydroxide and sodium chloride were used as the alkali and neutral salt, respectively. The water was purified (resistivity of 18 MΩ cm) using a Millipore direct-Q UV apparatus (USA).

2.2 Preparation of artificially soiled fabrics

We mixed 0.08 g Sudan III with 0.08 dm$^3$ oleic acid and applied ultrasound for 10 min. Then, we added 0.04 dm$^3$ dissolved homogeneous phase to 0.16 dm$^3$ ethanol. Carbon black (0.03 g) was ultrasonically dispersed in 0.2 dm$^3$ ethanol. Then, a piece of polyester fabric was immersed in the soil bath containing oleic acid/Sudan III or carbon black by applying ultrasound for 5 min. Twenty fabric pieces were soiled in the same bath. After soiling, the fabric was dried and then aged in a refrigerator for 7 days prior to the washing experiments. The surface reflectance of the original and soiled fabric was measured using a spectrophotometer (NF333, NIPPON DENSHOKU, Japan), stacking the same kinds of cloth in fours. The wavelengths used were 500 nm and 460 nm for the fabrics before and after soiling with oleic acid/Sudan III and carbon black, respectively. Each side of the cloth was read in two different spots and the average of those four readings was noted as the final value. The Kubelka-Munk function values, K/S, which were calculated from the surface reflectance, were within 0.9 ± 0.1 and 0.9 ± 0.2 for the fabrics soiled with oleic acid/Sudan III and carbon black, respectively.

![Fig. 1](image1.png) **Fig. 1** Experimental set-up of washing bath for ultrasonic washing.

![Fig. 2](image2.png) **Fig. 2** Photographs of mechanical actions fabrics before and after immersion in water (bath ratio 30) for 5 min without and with applying shaking and ultrasonic waves as mechanical actions.
2.3 Evaluation of detergency and soil redeposition

The washing test was carried out immediately after measuring the surface reflectance of the soiled fabrics (see 2.2). A soiled fabric and an original fabric were stacked with the soiled fabric on top and placed horizontally in a beaker (65 mmφ × 95 mm) containing an aqueous detergent solution. The detergent solution used was 1 mmol/dm³ NaCl, 1 mmol/dm³ NaOH and 1 mmol/dm³ NaCl, 8 mmol/dm³ AS and 1 mmol/dm³ NaCl, 0.3 mmol/dm³ AE and 1 mmol/dm³ NaCl, or 0.83 g/dm³ (standard dose) commercial detergent solution. The bath ratio was 10 or 30 (6 mL or 18 mL of detergent solution, respectively) and the temperature was 25 ± 1°C. As a source of mechanical action for soil removal, frequency modulated ultrasound (38 kHz, 80 W) was applied using a KAIJO ultrasonic cleaner utilizing a 64106 oscillator and a 64801VS washing bath (inner wall: 365 mm in length, 265 mm in width, and 245 mm in depth). The experimental design is illustrated in Fig. 1. The stainless steel 10 × 10 mm² mesh basket (315 mm in length, 230 mm in width, and 215 mm in height) was set in the washing bath 30 mm from the bottom with the water level of 68 mm. Four beakers were set in the bath. For comparison with the ultrasound, the washing test was carried out using Yamato BW201 shaking bath (inner wall: 500 mm in length, 300 mm in width, and 140 mm in depth). The four beakers were shaken simultaneously at 120 spm (40-mm stroke). After washing, the soiled and the original fabrics were rinsed separately for 60 s with 0.1 dm³ water and air-dried. The surface reflectance of the fabrics was measured as mentioned in 2.2, from which the K/S value was obtained. The detergency was calculated from the K/S values of the original and the soiled fabrics before washing and the soiled fabrics after washing. The difference in the K/S values of the original fabrics before and after washing was used as a measure of soil redeposition. All experiments were performed at 25°C.

2.4 Evaluation of fabric damage due to washing

To evaluate fabric damage, the following two test pieces were used: MA test piece cut into 50 × 50 mm² (a 35-mm circular hole was placed in the center) and the polyester fabric (50 × 50 mm²) similarly punched with a 35-mm hole. The test pieces and the original polyester fabric were immersed in water for 5 min with and without mechanical action as mentioned in 2.3. The test pieces before and after washing were also photographed.

3 RESULTS AND DISCUSSION

3.1 Effect of mechanical action on fabric damage

Figure 2 shows the MA test pieces and the polyester fabrics with a hole before and after washing. In ultrasonic washing, little damage was found, similar to the fabric after immersion without mechanical action. Therefore, it can be said that ultrasonic agitation causes little damage to the fabric in the textile washing process.

3.2 Effect of bath ratio and wash time on detergency and soil redeposition

Changes in the detergency and the redeposition of oleic acid/Sudan III for bath ratio of 10 and 30 with time are presented in Figs. 3 and 4. For shaking (Fig. 3), the detergency and soil redeposition increased with time and attained almost constant values. Soil removal was promoted and soil redeposition was prevented at the higher bath ratio. However, for ultrasonic washing (Fig. 4), the detergency increased drastically within a few minutes for both bath ratios. A comparison of Fig. 3 with Fig. 4 suggests that the ultrasound removed the oily soil efficiently at a low bath ratio and in a short time. However, soil redeposition after ultrasonic washing was larger than that for shaking. Soil redeposition can be influenced by soil concentration in the
detergent solution, the amount of soil removed from the fabric, and bath ratio. As expected, the soil redeposition corresponds to the detergency and bath ratio under the same condition in Figs. 3 and 4. This confirms that laundering at low bath ratios results in soil redeposition.

Photographs of the soiled and the original fabrics before and after the ultrasonic washing with bath ratio of 10 are given in Fig. 5. The oleic acid/Sudan III was removed unevenly from the polyester fabric and was deposited onto the original fabric. Cavitation is generated in localized regions on the fabric. The small-amplitude acoustic bubble oscillations and micro-jets resulting from the collapse of acoustic bubbles in the boundary layer between the fabric and the bulk fluid may cause the uneven soil removal and redeposition.

3.3 Comparison in detergency and soil redeposition between shaking and ultrasound in various detergent solutions

Figure 6 compares the detergency and soil redeposition of oleic acid/Sudan III between shaking and ultrasound in various detergent solutions. The detergency increased by the addition of alkali or surfactant. In all solutions, both the detergency and the soil redeposition were large for ultrasonic washing. As shown in Fig. 7, the detergency and redeposition of carbon black were considerably smaller than those of oleic acid/Sudan III. The detergency and redeposition with respect to mechanical action and detergent solution were similar to the results obtained for oleic acid/Sudan III (Fig. 6). Soil removal was enhanced by the addition of surfactant, and the detergency and the soil redeposition were both large for ultrasonic washing. As mentioned in 3.2, soil concentration in the detergent solution has a significant effect on soil redeposition. A comparison of the soil redeposition with the detergency in Figs. 6 and 7 shows that the soil was frequently deposited under favorable detergency conditions. For both oleic acid/Sudan III and carbon black, the soil redeposition was relatively small for detergency in the AS solution. On the contrary, the soil redeposition is promoted in AE solution. These findings suggest that the soil redeposition is prevented and promoted in the presence of anionic and nonionic surfactants, respectively.

4 CONCLUSIONS

By applying ultrasound, the oily and particulate soils were efficiently removed from the polyester fabric in a
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short time and at low bath ratio. In addition, the ultrasound caused little damage to the fabric during the washing. However, soil removal from the polyester fabric was uneven, and the removed soil was largely redeposited onto the fabric in the case of ultrasonic laundering. The mitigation of such uneven cleaning and of the soil redeposition are important aspects of future work with regard to the use of ultrasound for washing textiles at low bath ratios.

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Fig. 6 Detergency of polyester fabric soiled with oleic acid/Sudan III and soil redeposition onto original fabric after washing in various aqueous solutions of bath ratio 10 for 5 min with applying shaking (■) and ultrasonic waves (■) as mechanical actions.

Fig. 7 Detergency of the fabric soiled with carbon black and soil redeposition onto original fabric after washing in various aqueous solutions of bath ratio 10 for 5 min with applying shaking (■) and ultrasonic waves (■) as mechanical actions.

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