☘Detergency Study of the Synergism Between Oily and Particulate Soil on Polyester/Cotton Fabric

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The removal of multiphase, multicomponent soils from fibrous substrates depends upon the nature of the soil mixture, the order of application, wash temperature, and type of detergent formulation. By studying these factors, we investigated the synergism between residual oil (triolein) and particulate soil (clay) on a durable press polyester/cotton fabric after laundering with four different detergents at wash temperatures of 27 and 49 C.

To probe the interaction between clay and oil, fabric specimens were soiled with clay only, triolein only, clay followed by an application of triolein, and triolein followed by an application of clay. Four detergent formulations were used to launder the soiled fabrics, including one unbuilt liquid and three powdered detergents with different builder systems. The amount of residual oil (triolein) was determined by radiotracer technique, and the quantities of clay were determined by measuring aluminum by neutron activation. Reflectance measurements were used to calculate fabric whiteness. The soil distributions on and within the textile structure were obtained by scanning electron microscopy using backscattered electron images, secondary electron images and X-ray mapping. Osmium tetroxide was used to tag the oil, while silicon was the elemental tag for clay in the microscopic analysis.

Results of the four factors studied can be summarized as follows. (i) In agreement with observations by previous researchers, a mixture of clay and oil is more difficult to remove than either the oil or the clay applied singly. It appears that oil acts as a matrix to bind clay, forming a composite soil. (ii) The specimens that were soiled first with oil and then clay had more soil removed by laundering than the specimens soiled with clay and then oil. Detergency was limited by the encapsulation of clay by the oil and adsorbtion of oil by the clay. (iii) The built powdered detergents were temperature sensitive, while the unbuilt liquid detergent was not. (iv) The built powdered detergents removed more soil (oily and clay) than the unbuilt liquid detergent.

Particulate soil found on clothing is often covered with body sebum. This alters the surface characteristics of the particulate soil, making hydrophilic soils more hydrophobic. The liquid or solid oily soil encapsulating both particle and fiber can influence soil uptake, retention and washability (1). Particulate soil retention increases with the presence of sebum. The literature points out that the presence of oil in a mixed soil system may either increase (2) or decrease (3, 4) ease of removal of particulate soil.

Various components of multiphase, multicomponent soil are not always removed equally well. The quantity of individual soil components deterged depends on the nature of the soil mixture, the amounts applied and the order of application (1). Thus, analyses of the interaction of complex soils with fibrous substrates are necessary so that improved detergent formulations can be developed and recommendations for better laundry practices can be made.

Problems of soil removal are often coupled with current laundry practices which may involve the use of phosphate-free detergents formulated in response to environmental concerns and lower wash temperatures used to conserve energy. The type of detergent and the temperature of the wash water determine the extent to which laundry items approach acceptable levels of cleanliness and appearance during refurbishing.

This research characterized the synergism between oily and particulate soil. The order of application of oil and clay to a fibrous substrate was used as a diagnostic method to further the understanding of the soiling phenomenon. The effects of wash temperature and commercial detergent formulations with different builder systems on soil removal and fabric appearance were investigated. The distribution of residual soils on the yarn structure was studied by microscopy.

EXPERIMENTAL PROCEDURES

Fabric specimens. The experimental fabric, purchased from Testfabrics, Inc., Middlesex, NJ, consisted of a plain weave 65% polyester, 35% cotton blend with a durable press finish. Construction characteristics were as follows: fabric weight, 89 g/m^2; yarn number, 11.9 mg/m (warp), 12.0 mg/m (filling); yarn count, 3465 yarns/m (warp), 3307 yarns/m (filling); and yarn twist, 787 turn/m (warp), 709 turns/m (filling).

Sample preparation. Fabric squares, 12 cm × 12 cm, were zig-zagged by machine along the cut edges. Random groups of four specimens were then soaked in 900 cm^3 of a 10% w/v aqueous sodium chloride solution for 16 hr. The soak was followed by a Soxhlet extraction in deionized, distilled water for six hr. The samples were air dried at 21 C for 24 hr. Fabric specimens were brought to moisture equilibrium at the standard condition for textile testing (relative humidity of 65 ± 2%; temperature of 21 ± 1 C).

Detergents. Four commercial laundry detergents were tested. The detergents consisted of one unbuilt, liquid anionic/nonionic and three powdered anionic detergents with the following builder systems: a, trisodium nitrilotriacetate (NTA)/carbonate/zeolite; b, carbonate/zeolite, and c, phosphate/carbonate/zeolite. Before using, the powdered detergents were dried at 31 C for 15 hr and were then stored in desiccators to limit moisture pickup.

Soil and aging procedure. A significant fraction (32%) of natural soil is composed of triglycerides (5). Research (6) has shown that triglycerides are difficult to remove

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from fibrous materials; thus, triolein was selected as a model oily soil. Clay minerals are the major particulate materials that accumulate on fabrics during wear (1, 7). Kaolinite (Bandy Black), one of the most prevalent clay minerals, (1), was selected as a model particulate soil. The elemental composition of Bandy Black is silicon (21.7%), aluminum (20.9%), oxygen (55.8%), and hydrogen (1.6%), with trace amounts of other elements, as provided by H.C. Spinks Clay Company, Paris, Tennessee.

Four soil treatments were analyzed. Fabrics were soiled with either clay only (Bandy Black kaolinite); oil only (triolein); clay, followed by an application of oil (which will be referred to as the clay/oil treatment); or oil, followed by an application of clay (which will be referred to as the oil/clay treatment).

The nonradioactive oily soiling solution contained triolein with a concentration of 50 mg/cm^3 in toluene. The radioactive oily soiling solution contained triolein with a concentration of 50 mg/cm^3 in toluene combined with 560 μl of tritium labeled triolein stock. The reproducibility of application/aliquot was 0.03% (relative standard). The tritium labeled triolein [9,10-^{3}H(N)], with a specific activity of 111.1 Ci/mmol, was purchased from New England Nuclear, Boston, MA.

While fabrics were held in a plexiglass frame, a 200-μl aliquot of soiling solution was pipetted onto the center of each specimen. The average oily soiling level was 2.6% of fabric weight over a 43 cm^2 area. After the soiling solution was applied, the specimens were aged for eight hr at 38 ± 1 C, followed by four days at 21 ± 1 C.

Based on procedures by Kissa (8) and Morris and Prato (9), fabric samples were dry soiled with clay in an Accelerotor without an abrasive liner. Five specimens were soiled concurrently by operating the Accelerotor at 754 krad/s for one min, with an airflow of 42 l/min through the Accelerotor chamber.

Laundry procedure. Each sample was separately washed and rinsed, using an Atlas Launder-Ometer. All water was distilled and deionized before use. Based on commercial package recommendations, the detergent concentration was 0.100% w/v for the unbuilt, liquid and 0.175% w/v for the three built, powdered detergents.

Each sample was washed in individual 500 cm^3 capacity Launder-Ometer cans with 10 steel balls for 10 min, in 200 cm^3 of detergent solution. Two five-min rinses at 21 C in 200 cm^3 of water followed. The fabrics were laundered at wash temperatures of 27 C and 49 C. All samples were air dried at a temperature of 21 ± 1 C and a relative humidity of 65 ± 2%.

Color measurements. Visual appearance of the fabrics was determined with a Hunterlab D25 Color and Color Difference Meter. Specimens were allowed to come to moisture equilibrium at the standard conditions for textile testing. The values of L (lightness-darkness), a (greenness-redness), and b (yellowness-blueness) were taken. Five replicates were measured for each condition. In analyses of the data, color difference calculations and yellowness and whiteness indices all showed similar trends. As a result, the whiteness index was chosen for discussion of the experimental results. The whiteness index was calculated using the following formula (10): Whiteness Index = 0.01 L(L − 5.7b).

Total oil analysis by radiotracer technique. Liquid scintillation counting of tritium labeled triolein was used to provide a quantitative measure of the amount of residual oil present on the fabric specimens. An elliptical fabric sample with an area of 23.5 cm^2, cut from the center of each specimen, was placed in a scintillation vial with 20 cm^3 of toluene containing 5.0 g/l 2,5 diphenyloxazole and 0.1 g/l 1,4-bis[2-(4-methyl-s-phenyloxazolyl)]benzene (Fisher Scintiprep 1). Five replicates for each treatment were prepared. The radioactivity of each specimen was counted on a Beckman LS-7000 Liquid Scintillation Counter. The percent triolein removed from the treated specimens was then calculated.

Total clay analysis by neutron activation. Neutron activation analysis was used to provide a quantitative measure of the amount of residual particulate soil present on the fabric (11). Specimens were activated at the Ward Nuclear Laboratory at Cornell University, using the Rabbit Facility. Counts for aluminum at an energy level of 1779.14 KeV were analyzed and recorded on a ND 66 Multichannel Analyzer/Remote Terminal by Nuclear Data, Inc. In order to obtain the best resolution, clay specimens and standards were activated for one min at five kW. Oil/clay and clay/oil specimens and standards were activated for one min at one kW, to prevent them from becoming too radioactive. Counts were taken two min after the onset of neutron irradiation, for 200 seconds. The percent clay removed was then calculated.

Microscopic analysis. The distribution of oily and particulate soil was qualitatively determined by scanning electron microscopy. Secondary electron images were used to show the distribution of the clay particles on the clay only, clay/oil and oil/clay soiled samples. Backscattered electron images were used to study the distribution of triolein on the specimens soiled only with oil. Triolein was tagged with osmium tetroxide so that the distribution of oil on the polyester/cotton fiber matrix could be determined (12). Areas of high intensity of backscattered electrons (bright areas) in the micrographs indicate the location of osmium, and thus the oil. This is because the backscatter coefficient of osmium with a large atomic number is much higher than those of the elements in polyester and cotton (carbon, oxygen and hydrogen). Backscattered electron images could not be used to indicate the location of triolein on the oil/clay and clay/oil specimens, because the intensity of the backscattered electrons was also influenced by the presence of clay. As a result, elemental maps of the characteristic X-rays from osmium and silicon were used to indicate the locations of the oily (Os) and particulate (Si) soil on the clay/oil and oil/clay soiled specimens.

Longitudinal yarn sections were prepared for microscopic analysis, according to procedures described by Obendorf and Klemash (12). Data were collected on a JEOL JSM 35SF Scanning Electron Microscope, equipped with a Tracor Northern Energy Dispersive X-ray Analyzer. An accelerating voltage of 15 KV, a specimen current of 1.5 × 10^{-9} A, and a working distance of 15 mm were used.

The elemental maps were taken at a magnification of 4000×. The energy channels for X-ray mapping of silicon were set from 1.640–1.800 KeV. The energy of characteristic X-rays for silicon is 1.740 KeV. The energy channels for X-ray mapping of osmium were set from 1.810–2.020 KeV. The energy of characteristic X-rays for osmium is 1.910 KeV.

Statistical analysis. The statistical design of the experiment was a 4 (detergent formulations) × 4 (soil types) × 2 (wash temperatures) factorial. Analyses of variance were performed on the percent triolein and clay removed as measured by radiotracer and neutron activation analysis, and on the whiteness indices, as obtained from reflectance readings. The Waller-Duncan K-Ratio T Test was performed on all data sets to find where significant differences occurred among multiple means. A multivariant analysis of variance also was performed to determine if correlations existed between whiteness, triolein removal and clay removal. The statistical analysis was performed using the Statistical Analysis System (SAS) Package (13).

RESULTS AND DISCUSSION

Synergistic effect of oil and clay on fabric appearance and soil removal. Residual clay particles had a greater effect on fabric appearance than residual triolein (Table 1). Clay minerals are one of the soils that contribute to color change (7). These soils are naturally pigmented or can become pigmented by absorbing organic matter. Because of this, residual clay often gives fabrics an undesirable grayed appearance. Although there was a correlation between the percent clay removed and whiteness (r = +0.51), the correlation between the percent oil removed and whiteness was low (r = +0.11). Under the conditions of this experiment, residual oils did not have a significant effect on fabric appearance. The percent clay removed did not correlate well with the percent oil removed (r = +0.06). This suggests that oily and particulate soil are deterged by different removal mechanisms. The two soils also may be held in the fabric structure differently. Oil is integral to the yarn structure, and clay is found in crevices on yarn and fabric surfaces.

The low polarity of triolein, a triglyceride, may limit the degree of soil removal. Harker (6) provided microscopic evidence that polar soils are more easily removed than nonpolar soils. In the removal of fluid soil from cotton (4), polyester and cotton/polyester blends (5), researchers found that large quantities of free fatty acids could be deterged easily, but the removal of di- and triglycerides was much more difficult. This limit to

TABLE 1

Soil Removed and Whiteness Indices for Individual Soil Treatments

Soil treatment	Clay removed[a] (%)	Oil removed[b] (%)	Whiteness index[c]
Oil	-	41.7	100.7
Clay	82.8	-	80.2
Oil/clay	65.8	36.0	43.6
Clay/oil	54.2	22.9	56.0

Least significant difference (LSD) at α = 0.05.
[a]Clay: LSD, 2.58.
[b]Oil: LSD, 2.62.
[c]Whiteness: LSD, 0.80.

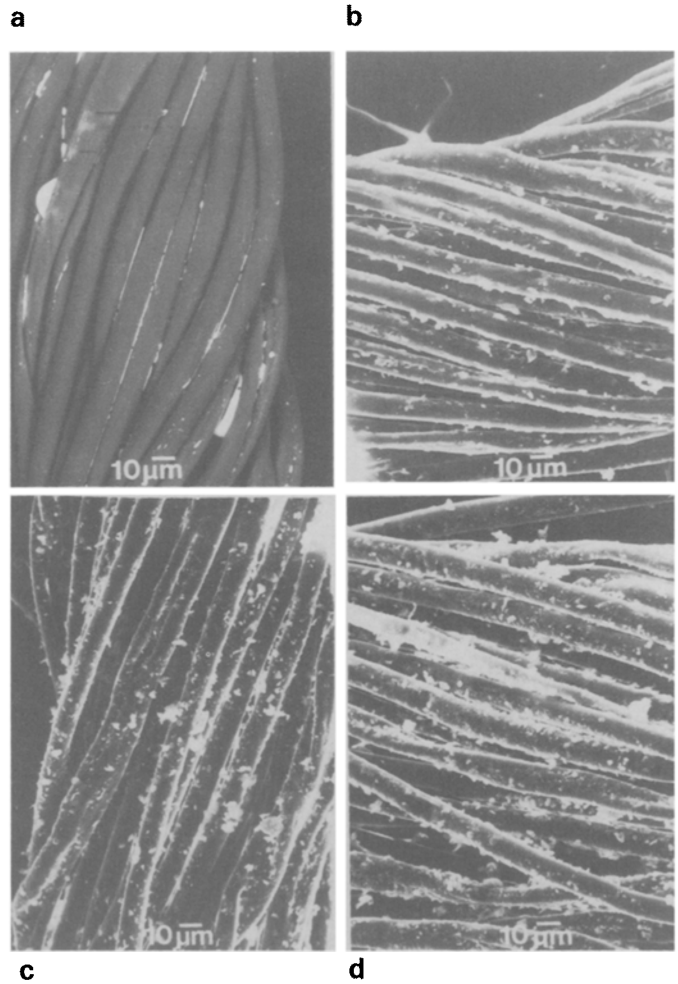


FIG. 1. A comparison of soil treatments: Yarns removed from unwashed specimens. a, Oil only (backscattered electron image); b, clay only (secondary electron image); c, clay applied before the oil (secondary electron image); d, oil applied before the clay (secondary electron image).

detergency may be due to little or no soap formation for these oils (12, 14).

The multicomponent soils (oil/clay and clay/oil) were less effectively removed from the fabric than either clay only or oil only (Table 1). It appears that the oil acts as a fatty matrix to bind the clay to fabric surfaces. This conclusion is in agreement with previous studies (15). Microscopy substantiates these claims. The unwashed specimens soiled with oil followed by an application of clay have higher initial levels of clay present on fiber surfaces than the other two clay treatments (clay only and clay/oil) (Fig. 1). Neutron activation analysis of the total amount of clay present on the unwashed specimens verified the microscopic observations (Table 2).

Micrographs of washed specimens also showed particulate soil entrapped within sheaths of oil, resulting in tenaciously bound soil (Fig. 2). The multicomponent soil of clay and oil was located in the crevices between the closely spaced fibers, which is the region where residual oil was observed in the oil only treated samples (Fig. 1a). Thus, it appears that clay is attracted to the oil, where it acts to absorb the liquid triolein.

TABLE 2

Amount of Clay Present on the Unwashed Specimens by Soil Treatment

Soil treatment	Mean[a] (mg clay)[c]	Grouping[b]
Oil/clay	24.3	A
Clay	12.2	B
Clay/oil	11.5	B

[a]Least significant difference, 1.2.
[b]Means with the same letters are not significant at the 0.05 α level.
[c]Amount of clay on a fabric area of 23.5 cm^2.

This property can be illustrated through the use of X-ray maps of silicon (the clay soil) and osmium (used as a tag for the oily soil) (Fig. 3). The high concentration of silicon corresponds as expected with the topography of the clay particles in the secondary electron image of an unwashed fiber (Fig. 3b compared to 3a). However, rather than being uniformly distributed over fiber surfaces, the triolein appears to be more concentrated in areas where the clay is located (Fig. 3c compared to 3b). This same trend is observed on the laundered specimens (Fig. 4). After washing, the triolein is still found in the same location as the clay. Similar findings were reported in studies of naturally soiled textile fibers (15, 16).

Thus, the clay binding properties of triolein and the oil absorbing properties of clay may explain why both oil and clay were more difficult to remove from the specimens which received the multicomponent soil, than from the samples treated with the single component soils, either oil or clay. Because the clay was firmly cemented to fabric surfaces by a layer of oil, the oil had to be at least partially removed before the clay soil could be deterged. Furthermore, because the clay was difficult to remove from the fatty matrix, the oil absorbed by the clay particles was also difficult to remove. The absorbed oil was not accessible to emulsification, solubilization or roll-up mechanisms.

FIG. 2. A backscattered electron image of an oil/clay treated yarn washed with unbuilt, liquid detergent at 27 C.

These characteristics (the oil-absorbing properties of clay, and the clay binding properties of oil) also have a

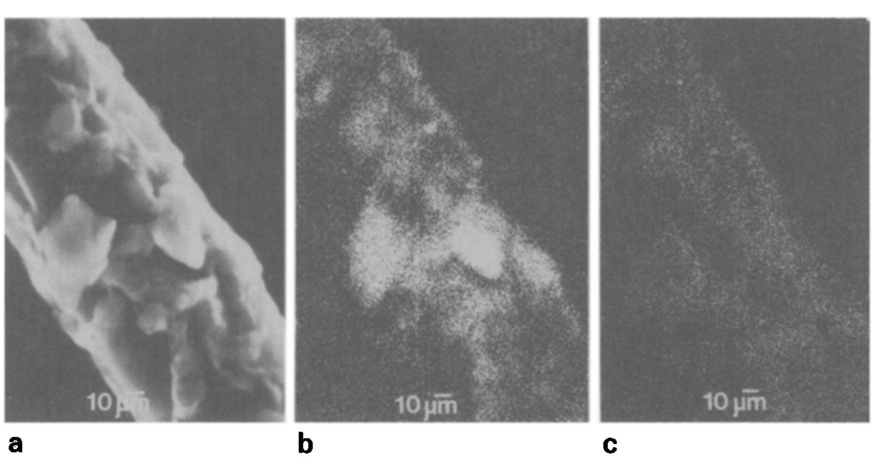
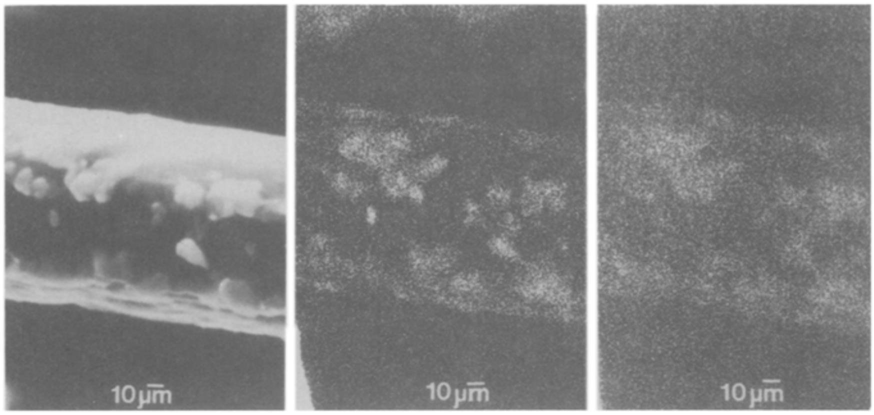
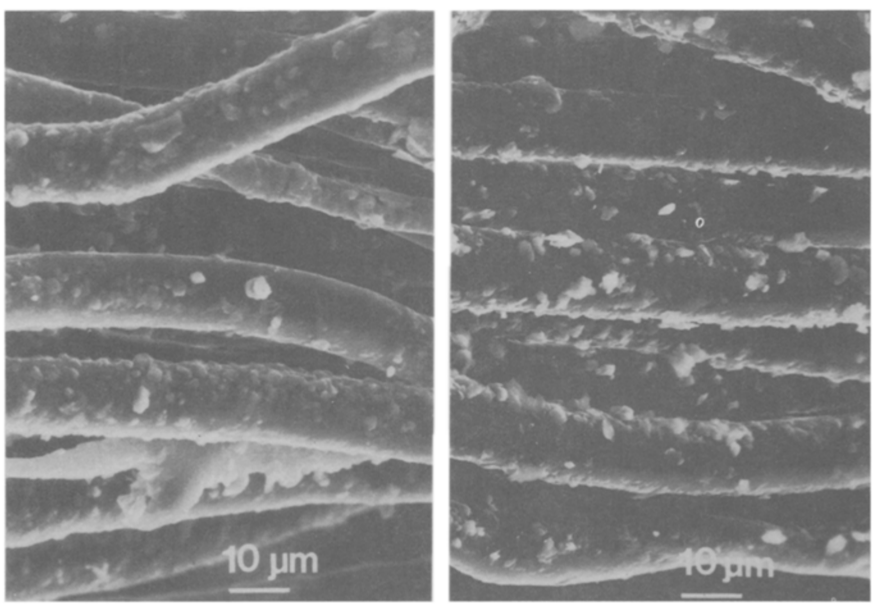


FIG. 3. Distribution of soils on an unwashed clay/oil treated fiber. a, Secondary electron image; b, X-ray map of clay (silicon 1.640–1.800 KeV); c, X-ray map of oil (osmium 1.810–2.020 KeV).



a b c

FIG. 4. Distribution of soils on a clay/oil treated fiber washed with unbuilt, liquid detergent at 49 C. a, Secondary electron image; b, X-ray map of clay (silicon 1.640–1.800 KeV); c, X-ray map of oil (osmium 1.810–2.020 KeV).



a b

FIG. 5. A comparison of multicomponent soil treatments: Secondary electron images of yarns washed in unbuilt, liquid detergent at 27 C. a, Clay applied before the oil; b, oil applied before the clay.

profound effect on the soil removal properties and appearance of fabric soiled with multicomponent soil. This effect is a function of the order of soil application. The clay/oil treated samples had less clay and oil removed from fiber surfaces than the oil/clay treated fabrics (Table 1). The clay particles on the clay/oil specimens were encapsulated by a layer of oil (Fig 5a), which firmly cemented them to fiber surfaces. The clay particles on the oil/clay specimens were able to protrude above fabric surfaces because the clay was applied after the oil (Fig. 5b). Thus, these clay particles were readily subject to agitator stress. Because the protruding clay particles (which contained absorbed oil) were easier to deterge than the encapsulated clay particles, more total clay and oil was removed from the oil/clay samples than from the clay/oil treated samples. However, even though the oil/clay treated specimens retained less residual soil than the clay/oil samples, the clay/oil treated fabrics looked cleaner (Table 1). A smooth surface will appear lighter than a rough surface. The fibers on the clay/oil samples were encapsulated with a layer of oil which resulted in a surface which was smoother than the surface on the oil/clay samples (Fig. 5). This upper layer of oil may also have blocked out some of the pigment from the Bandy Black clay, resulting in the clay/oil specimens appearing whiter than the oil/clay treated fabrics.

Effect of type of detergent formulation. More soil was removed with the built, powdered detergents than with the unbuilt, liquid detergent. The order of deter-

TABLE 3

Soil Removed and Whiteness Indices for Individual Detergent Formulations

Detergent formulation	Clay removed[a] (%)	Oil removed[b] (%)	Whiteness index[c]
NTA/carbonate/zeolite	79.9	41.6	80.6
Phosphate/carbonate/zeolite	75.3	37.6	77.0
Carbonate/zeolite	73.6	35.3	74.5
Unbuilt liquid	41.4	19.8	48.4

Least significant difference (LSD) at α, 0.05.
[a]Clay: LSD, 2.98.
[b]Oil: LSD, 3.04.
[c]Whiteness: LSD, 0.8.

gent efficiency was NTA/carbonate/zeolite > phosphate/carbonate/zeolite and carbonate/zeolite >>> unbuilt, liquid (Table 3). The effect of detergent formulation on soil removal was significant at the 0.0001 alpha level (Table 4). The data revealed that the cleaning efficiency of the NTA/carbonate/zeolite built system was only slightly better than the efficiency of the other two builder systems. Thus, the largest difference in soil removal and appearance between the formulations of detergents was based on the presence or absence of builders (Fig. 6, Table 3). For every soil condition which contained clay, fabrics washed with the unbuilt detergent had the lowest whiteness index (Table 5). Large quantities of residual clay present on these specimens are responsible for the darker appearance (Fig. 6).

It has been well documented that built, powdered detergents remove soil more efficiently than unbuilt, liquid detergents (9). There are many reasons why builders enhance the cleaning efficiency of the surfactant (17, 18). They sequester or precipitate hard water ions, emulsify oily soil and deflocculate, disperse and suspend particulate soil. They also serve as electrolytes to enhance surface activity. Although the unbuilt, liquid

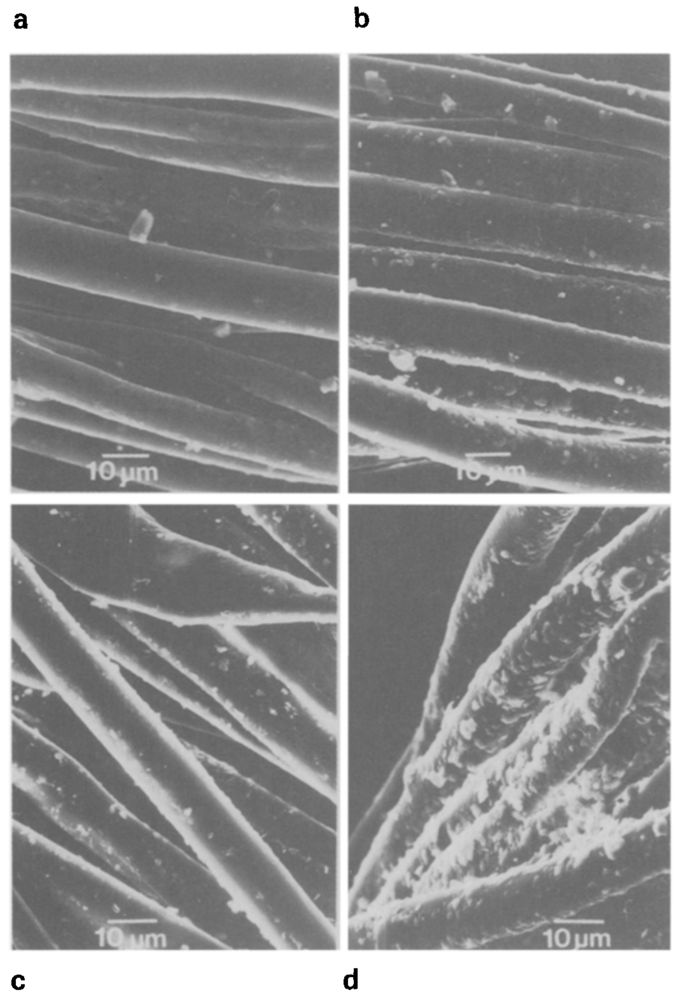


FIG. 6. A comparison of the cleaning efficiency of various detergent formulations: Secondary electron images of oil/clay removal at 27 C. a, NTA/carbonate/zeolite builder; b, phosphate/carbonate/zeolite builder; c, carbonate/zeolite builder; d, unbuilt, liquid.

TABLE 4

Summary of Analyses of Variance

Source	Oil removed F	Oil removed Pr > F	Clay removed F	Clay removed Pr > F	Whiteness index F	Whiteness index Pr > F
Soil[a]	82.3	0.0001	190.4	0.0001	6023.7	0.0001
Detergent[b]	61.5	0.0001	214.2	0.0001	2012.6	0.0001
Temperature[c]	28.7	0.0001	55.6	0.0001	746.1	0.0001
Soil × Detergent	1.1	0.36	29.4	0.0001	278.0	0.0001
Soil × Temperature	0.2	0.82	6.1	0.003	161.6	0.0001
Detergent × Temperature	3.8	0.01	6.8	0.0004	70.0	0.0001
Soil × Detergent × Temperature	3.1	0.008	1.4	0.23	21.5	0.0001

[a]Soil: clay only, oil only, clay/oil or oil/clay.
[b]Detergent, NTA/carboante/zeolite, phosphate/carbonate/zeolite, carbonate/zeolite, or unbuilt liquid.
[c]Wash temperature, 49 C or 27 C.

TABLE 5

Whiteness Indices and Percent Soil Removed From Laundered Specimens at Wash Temperatures of 49 C and 27 C

Detergent formulation and wash temperature	Clay only[a] % Soil removed	Clay only[a] Whiteness index[b]	Oil only[c] % Soil removed	Oil only[c] Whiteness index[b]	Oil/Clay % Soil removed clay[a]	Oil/Clay % Soil removed oil[c]	Oil/Clay Whiteness index[b]	Clay/oil % Soil removed clay[a]	Clay/oil % Soil removed oil[c]	Clay/oil Whiteness index[b]
NTA/carbonate/ zeolite										
49 C	85.5	90.6	55.1	100.3	86.9	44.0	73.1	78.4	34.4	78.5
27 C	85.5	86.3	40.2	101.2	79.8	41.5	46.5	63.4	34.2	68.5
phosphate/carbonate/ zeolite										
49 C	87.7	93.4	50.3	100.0	84.0	43.5	63.2	77.1	25.6	69.7
27 C	84.5	82.9	37.6	102.0	64.1	31.4	44.1	54.3	23.1	60.8
carbonate/zeolite										
49 C	88.8	88.3	51.0	100.2	79.1	45.1	63.5	71.3	33.1	75.9
27 C	79.0	78.6	40.3	100.5	66.7	39.0	35.5	56.8	16.9	53.4
unbuilt liquid										
49 C	75.5	60.3	25.6	101.1	34.3	23.2	12.4	16.0	10.7	23.2
27 C	75.7	61.3	33.5	100.3	31.2	20.0	10.4	16.0	5.6	18.2

Least significant difference (LSD) at α, 0.05.
[a]Clay: LSD, 7.4.
[b]Whiteness Index: LSD, 2.3
[c]Oil: LSD, 7.6.

detergent contains surfactants which can emulsify oily soil and suspend particulate soil, the synergistic effect of surfactant and builder is greater than that of surfactant alone. In addition, at the higher pH of built detergents, soap formation can occur which aids in the removal of other soils (14).

There were few differences in the cleaning efficiency of the three powdered detergents in this study (Table 3), partly because samples were washed in distilled, deionized water. Different findings would have been expected if the samples were washed in hard water (17, 18). The cleaning ability of the detergent containing NTA is approximately equal to that of detergents containing sodium tripolyphosphate (18). In hard water, carbonate built detergents are not as satisfactory for cleaning as detergents with phosphate or NTA builder systems, because carbonates cannot reduce the concentration of calcium ions as effectively (17). As a result, more calcium ions are present in the wash water, reacting with the surfactant, thus lowering the efficiency of the detergent.

Effect of wash temperature. When laundering with built, powdered detergents, more soil was removed at the higher wash temperature (Table 5). Generally for these powdered detergents, the higher wash temperature resulted in better appearance for all soil treatments containing clay (Table 5). Appearance of fabrics washed with the unbuilt, liquid detergent was not temperature dependent.

The largest improvement in oil removal with the higher wash temperature was observed for the fabrics treated only with oil (Table 5). Changes in wash temperature are known to affect oily soil detergency (1, 9). Fatty soil is more easily removed at higher temperatures because of increased thermal currents and reduced oil viscosity (19). Scott (14) found that although the rate of removal of triglycerides below their melting point was small but constant, there was a sudden increase in the amount of oil removal at the melting point of the triglyceride. Although both wash temperatures used in this experiment were above the melting point of triolein, significantly more oil was removed at 49 C than 27 C for all built powdered detergents. Improvements in triolein removal for the multicomponent soils were not as large (Table 5). This could be due to adsorption of oil onto the clay structure, thereby limiting oil removal by the roll-up mechanism.

In comparison, the greatest improvement in clay removal with an increase in wash temperature was observed for the clay/oil treated fabrics, followed by the oil/clay, then clay only treated specimens (Table 5). The temperature responsive characteristics of triolein may be responsible for this relationship. The upper layer of the fatty matrix on the clay/oil treated specimens may have been depleted to a greater extent by the higher temperature, which allowed more clay to be removed. Soil removal from the specimens treated only with clay was not influenced by temperature as much as the multicomponent soils or single component oily soil (Table 5). Morris and Prato (9) have reported a similar finding.

Our further detergency research investigates the effect of the textile substrate on removal of natural soils composed of oil and clay components. Specific factors are fiber blend level in cotton and polyester fabrics and functional finishes such as durable press and soil release (20). There are important questions in the area of soil release relative to detergency.

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