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EFFECT OF WATER PH ON DOMESTIC MACHINE WASHING PERFORMANCE OF DELICATE TEXTILES

Nilüfer Çakmakçı[1]*, Cevza Candan[2], Başak İlkiz Arslan[3]

1 Department of Organic Materials and Fiber Engineering, Soongsil University, Seoul 06978, Korea
2 Istanbul Technical University, Textile Technologies and Design Faculty, Department of Textile Engineering
3 Arçelik Incorporation, Department of Product Training, HQ, Sütlüce, 34445 İSTANBUL
*Corresponding author: nlfrckmkci@gmail.com

Abstract:

In order to investigate the effect of washing water pH on textile damage for delicate garments, the study was conducted such that a customer survey was first applied to randomly selected users to analyze domestic washing machine using habits of Turkish consumers. Based on the findings of the survey, the experimental study was designed in two successive phases to investigate the dimensional and mechanical behavior of certain types of delicate textiles against varying washing conditions by taking in particular, water properties, namely pH, hardness, and temperature into account, and accordingly to determine the optimized washing conditions for such textiles. Firstly, tergotometer was employed as a washing machine simulator. Within the light of the results obtained, the experimental work of the second phase of the study was conducted, which involved a domestic washing machine as a real-life scenario. All of the results, including the correlation between the data sets obtained from the tergotometer and domestic washing machine trials, were statistically analyzed using Minitab 17. The study produced some important findings regarding the effect of washing water pH on delicate textiles, in addition to an algorithm for improving the present washing program, minimizing textile damage for mainly wool and silk garments.

Keywords:

Domestic washing machine, water pH, tergotometer

1. Introduction

Washing of clothing in domestic laundering machines is influenced by physicochemical and mechanical actions. The physicochemical action plays a role in separating soil from clothes and dispersing it into the detergent solution, whereas the mechanical action facilitates separating soil from textiles by flexing and inducing friction between textiles, moving loosened soil to the detergent solution, and delivering fresh detergent solution to the textile surfaces [1-4]. Based on the classification of the mechanical actions of washing (i.e. large-scale, small-scale, and molecular scale), movements in a washer are large-scale and small-scale effect, and affect textiles in terms of tensile strength and shearing stress by textile flexing and detergent flux [3,5]. So, the control of these forces for an effective washing in a washer is mainly regulated by the parameters of wash spin speed, on/off time of motor, washing time, and water amount [3,4,8-13]. However, the wet rubbing and beating operations essential to effective cleaning are partly responsible for the deterioration in textiles that have been washed. The fabric changes that occur during washing, such as shrinkage, distortion, fiber damage, fabrics becoming stiff and harsh, color fading, and cross-staining by fugitive dyes, are all also dependent on fiber type, fabric construction, dye class, and the fabric finishing processes applied and production method.

Over the years, innovation drives the apparel market providing consumers with an increasing array of products to choose from, including the products that are made from established luxury fibers namely silk and wool and their blends, but are used in non-traditional ways such as next-to-skin knitwear and/or various types of much lighter garments for trans-seasonal daily wear. In addition to that, the modern lifestyle has created an increased consumer demand for machine washability of almost all textiles, including the delicate ones [14]. Obviously, delicate textiles are more susceptible to the aforementioned mechanical actions in a washer than the others, i.e. cotton, linen garments, etc. Silk textiles, for example, crease and dimensionally deform easily during conventional home laundering [15]. Wool, on the other hand, is a unique fiber and the only one that has a tendency to shrink or "felt" due to unidirectional external forces when agitated in the presence of water [16]. Literature offers several alternative studies on damage-free cleaning solutions for delicate textiles such as silk [1,3,15,18-21], and some more on laundering conditions of wool from the perspective of felting. Those studies show that in domestic washing machines, variations in the pH and temperature of the solutions can cause large differences in felting rates, especially of wool made shrink resistant by oxidation procedures, and that in general, felting rate of treated wool decreases with increasing pH and temperature of the solutions, the relative effects of given changes in the composition of the solution usually being greater with treated than untreated wool [20,22]. Also,

for improved wash-and-wear appearance of various types of textiles, there are many researches focused on the influence of washing conditions (i.e. water temperature, agitation, etc.), including hygiene related factors, in addition to the gentle action appliances developed by machine manufactures as well as the introduction of more effective detergent systems that ensure the removal of soil and stains without the robust mechanical action of traditional washing machines [9,14,19,23-26]. However, in these studies, water quality is mostly limited with water hardness, and to the best of our knowledge, there is lack of representative data available regarding the effect of wash (detergent + water solution) pH on textile damage in the laundry process, despite the fact that it may cause deterioration in wool/silk-based textiles by repeated washing and/or elevate desorbed dye increase in the bath as a result of detergent selection, changing consumer laundry habits, and/or combination of both [26,30-39].

Accordingly, the current study was conducted: a) to systematically examine the influence of water pH, together with the other washing parameters, on textile wear. In doing so, particular attention was given to textiles from specialty protein fibers such as silk and wool, as they are becoming increasingly popular for products intended for every-day consumer use; b) to investigate if tergotometer can be used as a laundering simulator for delicate textiles; and finally, c) to collect data on laundering performance of delicate textiles for improving hand wash and/or wool programs for domesting laundering machines as further work.

2. Experimental

As a base for the experimental design of the study, a survey was conducted using a structured questionnaire to identify Turkish consumers' laundry habits, including cleaning behaviors toward delicate textiles. The survey was applied, face-to-face, to the participants who were randomly chosen from the pool of domestic washing machine users living in different districts of İstanbul. The regions for the survey were determined such that they were the most populated areas in İstanbul, having the people coming from diverse economic and cultural backgrounds. After the questionnaires of non-consistent respondents were eliminated, the results obtained for 291 participants (201 females and 90 males) were taken

into account for subsequent analysis. The discussion of the analysis is out of the scope of the current study. However, the most important results regarding the experimental design devised for the current study are given as follows:

1. 64% of the participants prefer domestic laundering machines to wash their delicate textiles (wool, cashmere, etc.).

2. 41% of the participants do avoid using the domestic washing machines for silk garments.

3. For the majority of the respondents, washing temperatures of 30 and 20°C are the most popular ones so far as delicate textiles are concerned.

4. For delicate textiles, 57% of the participants use a wool/silk washing program, whereas 40% prefer the "hand wash" washing program in the machines.

5. The main problems faced by the participants are pilling and dimensional changes for wool textiles, whereas it is the wrinkling and loss of texture for silk textiles.

6. The quality and type of detergent are perceived as having a critical impact on garment quality, and accordingly, for preventing textile damages, including the delicate ones, 59.8% of the participants use liquid detergents.

In light of these findings, the material and method of the study were detailed and are given in the following sections.

2.1. Materials

For the study, three different fabrics made from wool and silk were used as test samples. Table 1 presents the general properties of the test samples used. All test sample fabrics did not have any special finishes, and they were conditioned at 55% ±5 relative humidity and 23°C ±2°C temperature for 24 hours before the textile quality tests were conducted.

The test sample-1 is used for testing the dimensional performance of knitted wool textiles in accordance with ISO 6330:2012 Textiles – Domestic washing and drying procedures

Table 1. Properties of the test samples

Test sample type	Raw material	Fabric construction and design	Basis weight of fabric	Certification
Test sample-1	100% high-quality Merino Wool	1 × 1rib knit	273 g/m²	Supplied from AWI (Australian Wool Innovation Ltd.). Used for Woolmark Apparel Care Certification of Tumble Dryers
Test sample-2	100% wool	Plain weave	138 g/m²	Supplied from Swissatest, Sample Code 318 Wool Shrinkage Test Fabric IWS-Wool SM-12 Test Cloths
Test sample-3	100% silk	Plain weave	67 g/m²	Custom-made for the study

for textile testing. For the work, it was selected to simulate real-life knitted wool garments such as jumpers and scarves.

The test sample-2 is employed as standard wool fabric for testing the dimensional performance of woven wool textiles in accordance with BS EN 60456:2011 Clothes washing machines for household use — Methods for measuring the performance. This woven wool fabric sample was utilized as a representation of woven wool garments/accessories such as pants and skirts.

100% silk woven fabric, which is coded as test sample-3 in Table 1 is concerned, was supplied from a local silk fabric producer as there is no standard silk fabric for testing textiles in domestic washing machines. The structural properties of the fabric (the warp density is 28 ends/cm and weft density is 26 picks/cm, the yarn linear density is 13 tex without no twist) were determined such that they were as close as to those of the silk textiles such as silk scarfs, blouses, and shirts washable in domestic laundering machines. Moreover, because 100% knitted silk garments are very rare in the market, only woven silk fabrics were used for the work.

For domestic washing machine tests, polyester base load fabrics are used to achieve a maximum load of washing program of 2 kg. The details of the base load can be found in ISO 6330:2012 Textiles - Domestic washing and drying procedures for textile testing standard base load.

For evaluating the washing performance of woolen programs, standard stain strips from Swissatest specially designed for use in washing machines were employed.

There are four stained standard wool fabrics (namely red wine, chocolate milk, blood, and carbon black stain) and one control fabric on the lacquer strip. To assess washing performance in accordance with BS EN 60456 - Clothes washing machines for household use - Methods for measuring the performance, tristimulus Y reflectance measurements are carried out on each of the individual soil types and the unsoiled test piece, which makes up the stain test strip. Reflectance measurements are taken of the same washed soil type [40].

For the work, a commercially available liquid laundry detergent from the detergent market was selected based on the findings obtained from the questionnaire mentioned above.

For the experimental work, the water was conditioned in accordance with EN 60734:2012- Household electrical appliances. Performance. Water for testing standard. The process may be summarized as follows: The tap water was taken from the water supply network and treated in a reverse osmosis unit to transform pure water in a vessel. After that, the water was transported to another vessel for chemical dosing so that the water hardness of 15–16 °dH German values and pH value of 7.0 could be achieved. In order to eliminate the detergent effect on pH, which is known as a dominant factor, detergent was first added into wash liquor, and then, the desired pH values of the water (i.e. 6.0, 7.5, and 9.0) was regulated using HCl and NaOH.

2.2. Equipment and Devices

Washing Equipment and Programs: For the washing tests, both tergotometer from Copley Scientific which is used to simulate of domestic washing machine in small-scales, similar to the applications in the literature and a domestic washing machine for the real-life scenario were employed [4,6,31,41].

The tergotometer has a single-drive mechanism that stirs eight reservoirs simultaneously, and the temperature is adjustable. All reservoirs have 1,000 mL liquid capacity. The temperature can be raised up to 70°C, and the speed (rpm) is within the range of 50 to 200 rpm. For the study, the speed of the tergotometer was set to 52 rpm, and the whole capacity, namely 1,000 mL, was utilized. The domestic washing machine used, on the other hand, was a front-loading type with a capacity of 9 kg, and the spin speed of the wool washing program was 800 rpm (see Table 2).

The washing data of the wool program in the domestic washing machine (i.e. temperature from inside of both the drum and heater, rotation of the drum, water intake amount, power, energy, current, volt, and time) are given in Figure 1-a, collectively. The details of the hand wash program selected for silk samples, however, are presented in Figure 1-b.

Similar to the wool washing program, the mechanical effect was at the lowest level in the hand washing program. The main wash water amount was the same as the wool program, which was 11 L. Also, the water amount for the first rinse step was 10 L, whereas it was 12 L for the second rinse step.
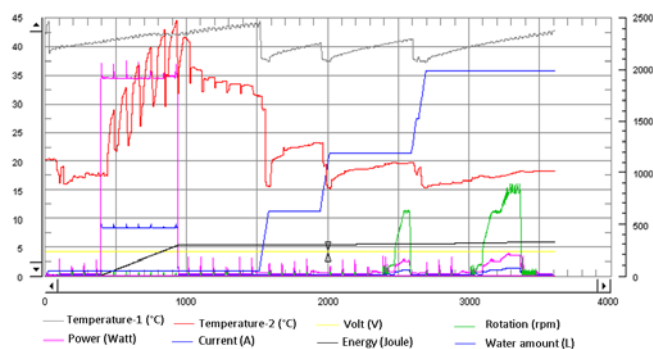
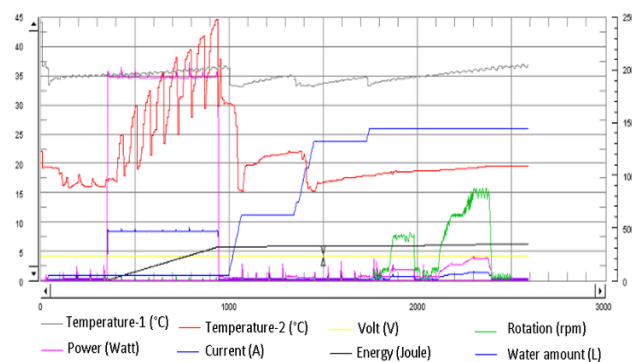**Table 2.** Washing Equipment Settings

Tergotometer

Test Step	Duration (min)	Temperature (°C)	Rpm
Main wash	30	30, 40	52
1st rinse	5	20	52
2nd rinse	5	20	52

Washing Machine

Wool program	58	40	35
Hand washing program	41	40	45

A. Wool program.

B. Hand wash program.

Figure 1. The details of wool (a) and hand wash (b) programs

For water measurements; pH meter, water hardness kit, and water conductivity meter were used, whereas for the fabric measurements Datacolor Spectrophotometer, bursting strength tester, and textile tensile strength tester were utilized. The measuring devices are listed below:

- Water pH measurement: Mettler Toledo, S220-KIT pH/Ion Seven Compact.

- Water conductivity measurement: HACH, HQ40d.

- Water hardness measurement: HACH, Total hardness test kit model 5-B.

- Spectrophotometer device for color measurement of wool and silk fabrics: Datacolor 600 Spectrophotometer. Spectrophotometer was also used for reflectance measurements of wool stain strips.

- Measurement of tear strength of woven wool and woven silk fabrics: Titan2 - Universal Strength Tester Machine.

- Measurement of bursting strength: PnuBurst™ Pneumatic Bursting Strength Tester.

2.3. Method

The designs of an experiment for the two phases of the study, i.e. small-scale tests (tergotometer) and real-life scenarios (domestic washing machine), were done at two washing temperatures (30°C and 40°C) and different pH values. Three pH values were selected to simulate acidic (pH 6), real-life scenario (pH 7.5), and basic condition (pH 9) for both tergotometer and domestic washing machine tests.

For tergotometer tests, Sample-1 (knitted wool fabric), Sample-2 (woven wool fabric), and Sample-3 (woven silk fabric) were washed separately at 30°C and 40°C, and three different pH values (pH 6, pH 7.5, and pH 9). For domestic washing machine tests, because there is wool program in the machine, Sample-1 (knitted wool fabric) and Sample-2 (woven wool fabric) were washed together with the recommended wool program, while Sample-3 (woven silk fabric) was washed separately with the recommended hand wash program. All

domestic washing machine testes were done at 40°C and three different pH values (pH 6, pH 7.5, and pH 9).

The design of experiment for the real-life scenario (i.e. domestic washing machine tests) was conducted in accordance with the data obtained from the tergotometer tests. The spin cycle, wash time, and water intake values of the washing programs (i.e., wool and hand wash programs) were kept constant.

Tergotometer tests were repeated 10 times for each condition to simulate 10 consecutive washing cycles in real life. In tergotometer tests, after the first, fifth, and tenth washes, the dimensional stability and color change performance of the samples were tested. Also, the washing water parameters, namely water pH value, hardness, and conductivity, were measured before and after each wash in tergotometer tests to keep the parameters of tergotometer washing system under control. In addition to these measurements, the tear strength and bursting strength of the samples were tested at the end of the fifth as well as the tenth wash.

When it comes to washing machine tests, at the end of the first and fifth washes, dimensional change measurements were repeated. Adding to these measurements, after the fifth cycle color measurements, tear strength and bursting strength were measured. Similar to the tergotometer washing tests, the washing machine water characteristics (i.e., water hardness, pH value of water, and water conductivity) were also continuously kept under control.

All the results were statistically analyzed using Minitab 17 statistical software and using ANOVA, which is analysis of variance, to find out the effect of parameters on dimensional change, tearing, and bursting strength for tergotometer tests. In addition to that, two-way interactions of the main parameters and the main effects of these parameters were also studied for tergotometer tests. Moreover, the correlation between the data collected from the tests using tergotometer and domestic washing machine were analyzed in order to investigate if tergotometer can be used as a simulation device of the washing machine to reduce water and textile material waste.

Following the statistical analysis of the data collected from the samples laundered using two different washing devices, namely tergotometer and domestic laundering machine, the

correlation analysis is performed between these two sets of the data for each parameter (i.e., bursting strength, tearing strength, and dimensional change) using Minitab software.

3. Results and Discussion

3.1. Dimensional Stability

ANOVA analysis showed that the variables pH value, number of washing cycle, temperature, and sample type are influential for dimensional change (the p values ≤ 0.05) and the R-square for statistical analysis of dimensional stability was 96.02%. Adding to this, the two-way interactions were 0.006 for pH value – washing cycle, 0.000 for washing cycle – water temperature, 0.000 for washing cycle – sample type, and 0.007 for water temperature – sample type.

Furthermore, the distribution of the effective parameters (for tergotometer tests) on dimensional change revealed that the number of washing cycles (44.5 %) is the most significant factor, which is followed by sample type (34 %) and temperature (6.8 %). The effect of the pH value of the washing water, however, is 1.9 %. The ANOVA also suggested that irrespective of the sample type (i.e., knitted or woven), dimensional change increases as the water pH value, washing cycles, and temperature increase. Two-way interactions of the relevant data demonstrated that the effect of both pH value and water

temperature on dimensional change become more significant as the number of washing cycles is increased.

As the pH level decreases, the dimensional change decreases, and the tendency is very similar for washing machine and tergotometer, as given in Figure 3.

Finally, so far, as both of the washing equipment (tergotometer and domestic washing machine) used for the work are concerned, the statistical analysis of each sample leads to the fact that relatively lower pH levels of washing water are needed for better dimensional stability (see Figures 2 and 3).

3.2. Tearing Strength

The tearing strength results in both warp and weft directions of the woven wool and silk fabrics were statistically analyzed and the R-square value was 93.52%. The ANOVA test results revealed that each parameter as well as their two-way interactions have an influence on tearing strength performance of the relevant samples (i.e., Samples 2 and 3); the p value for all main factors, which are sample type, temperature, pH value, and washing cycle, were 0.000, and the p value of two-way interactions was 0.011 for sample type – pH value and 0.001 for water temperature – washing cycle.

The results and statistical analysis for both warp and weft directions have a similar pattern. For simplicity purposes, only the results obtained from the warp directions are discussed in this article. The distribution of the effective parameters on the tearing strength performance of the samples demonstrated that irrespective of the measurement direction (i.e. warp and weft), the sample type (see Table 1) is the most effective parameter (76.6%), which is followed by the number of the washing cycles (11.1%). The effect of the pH value of the washing water is, on the other hand, found to be more significant in the warp direction (2.5%), when compared to the effect on the weft direction (1%).
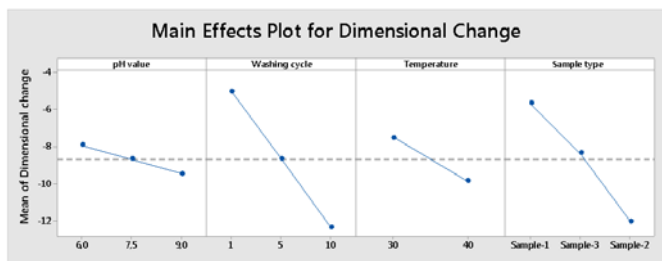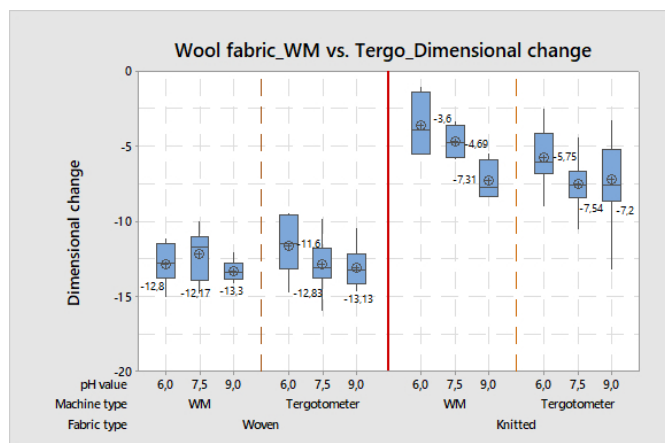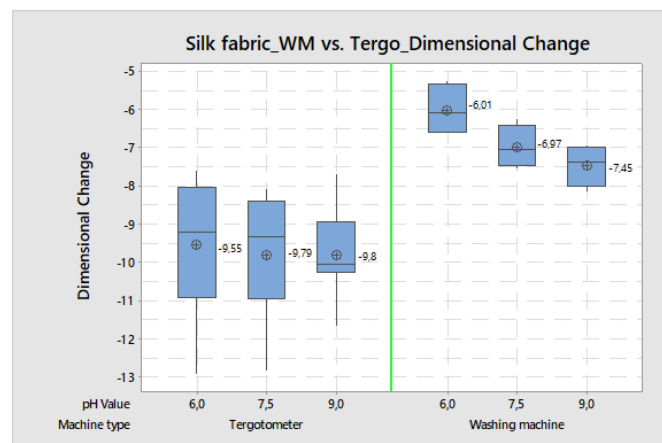

Figure 2. Main effects of dimensional stability.

A. Woven and knitted wool fabric

B. Woven silk fabric.

Figure 3. Dimensional change of (a) woven and knitted wool fabric, (b) woven silk fabric in warp direction after 5 washes at 40°C in tergotometer versus washing machine
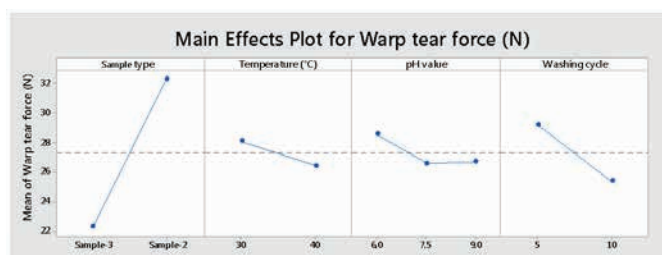
Figure 4. Main effects plot for tearing strength in warp direction

As given in Figure 4, the further statistical analysis of the main parameters suggested that the tearing strength in both directions decreases when temperature, number of washing cycles, and the pH value of washing water does increase. Moreover, the results obtained implied that the tearing strength tends to slightly drop when the wash pH is set at the value of 7.5 (see Figure 4).

Finally, after five washes at 40°C using a domestic laundering machine, the tearing strength performance of the samples is similar to that of the samples washed using tergotometer (see Figure 5 (a–b)).

3.3. Bursting Strength

This evaluation involves Sample 1 – knitted wool only. The R-square value was 86.07%, together with the p values (≤ 0.05), which demonstrated that each parameter, including their two-way interactions, affects the bursting strength performance of the relevant sample. All main factors (temperature, pH value, washing cycle) and the two-way interaction of the water temperature–washing cycle have 0.000 as a p value. Also, the p value for the two-way interaction of the water temperature–pH value was 0.003, and for the two-way interaction of the pH value-washing cycle was 0.011.

Furthermore, the number of washing cycles is the most effective parameter (51.7%), which is followed by the pH (14.9 %) and the temperature (10.6%). So far, as the two-way interactions

are concerned, it is the temperature and number of washing cycle interaction that is the most significant one, with 7.2 %. The statistical analysis of the main parameters revealed that the bursting strength decreases when the temperature, number of washing cycles, and pH value of washing water do increase.

Moreover, the analysis also showed that an increase in the temperature or the number of washing cycles makes the effect of pH value more prominent (see Figure 6).

As a final word, the p values obtained for the Pearson correlation were well below 0.05, and a positive and strong relationship between the washing devices under discussion (the Pearson correlation is within the range of 0.70 (bursting strength) to 0.926 (dimensional change) was observed, which may suggest that tergotometer can be used to test the effect of laundering parameters such as pH, temperature, and number of washing cycles on the damage of delicate textiles.

3.4. Washing Performance

In this section of the work, the effect of water pH value on the washing performance of the wool program was investigated. To
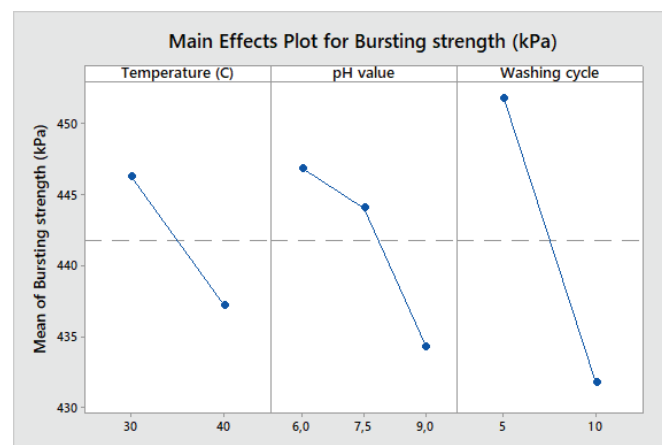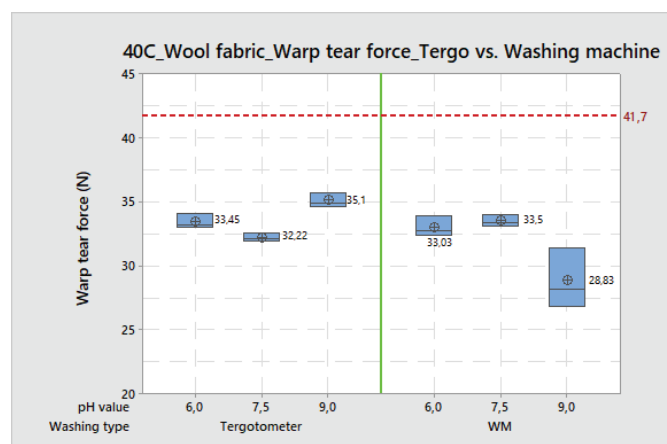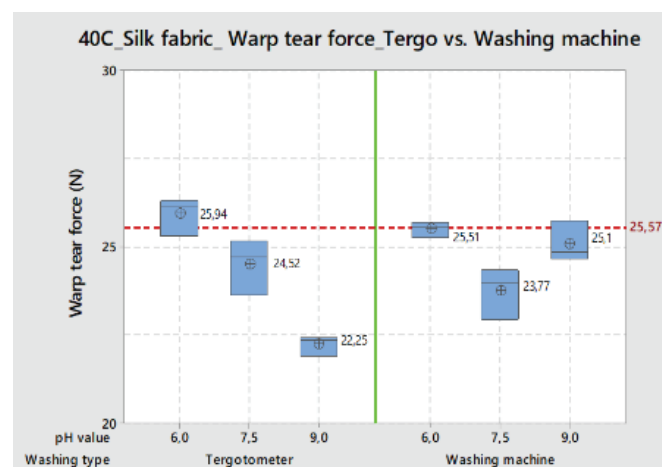

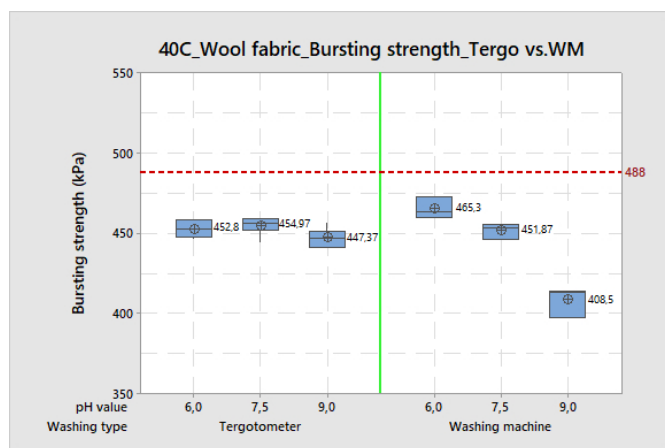**Figure 6.** Main effects plot for bursting strength

A. Woven wool fabric
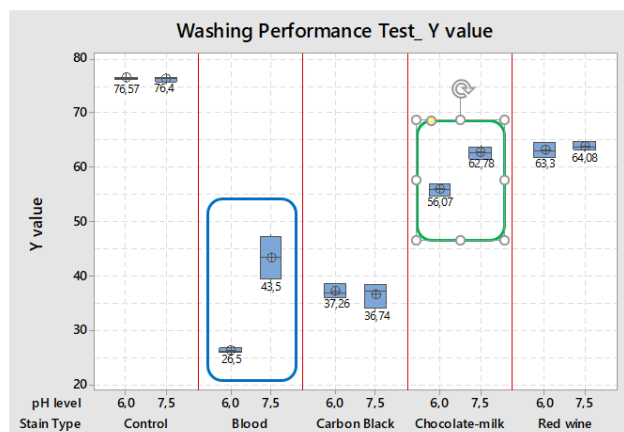

B. Woven silk fabric

Figure 5. Tearing strength of (a) woven wool fabric, (b) woven silk fabric in warp direction after 5 washes at 40°C in tergotometer versus washing machine

Figure 7. Bursting strength of knitted wool fabric, after 5 washes at 40°C in tergotometer versus washing machine

Figure 8. Y values of washing performance test

do so, the wool-stained test strips were washed in the woolen program at 40°C. The water pH values were selected as 6 and 7.5. This was mainly because the experimental study revealed that the textile damage is much less at the water pH value of 6. The pH 7.5, however, was taken as the reference state for the domestic laundering process, as it was the value measured after adding the liquid detergent into the conditioned water. The stain removing performance was measured from tristimulus Y reflectance values of the washed stain strips, with the help of a Datacolor spectrophotometer.

Figure 8 presents that the protein-based blood and chocolate milk stains performed worse at pH 6, in comparison to pH 7.5. However, the non-protein-based stains such as carbon black and red wine showed almost similar performances, independent of the pH value of the washing medium. This is mainly because different stain types need different chemicals to remove from the textile surface. Laundry detergents contain various chemicals such as surface active agents, brighteners, enzymes, and other chemical agents to stabilization [42]. Surface active agents remove oil-based stains, and bleachers in laundry detergent remove colored stains such as red wine, coffee, and tea stains. When it comes to enzymes, which are the key element for removing protein-based stains, they have very sensitive activation conditions. One of the most important

parameters to enzyme activation is the pH level. Amylase and protease enzymes are common detergent enzymes in the laundry detergent market. These two enzymes generally have an optimum pH level at the alkaline region [43,44]. Consequently, these enzymes cannot work efficiently to remove protein-based stains at acidic pH values. So, at the washing water pH level of 6, the washing performance of protein-based stains, which were blood stain and chocolate milk stain in the study, decreased dramatically compared to the other types of stains.

3.5. Color Change

All of the color change measurements were made using the spectrophotometer. For the samples washed using tergotometer, the color change measurements were repeated after the first, fifth, and tenth laundering cycle, whereas for the samples treated using the washing machine, they were made after the fifth cycle only. The Y value of the knitted wool and woven wool fabric increased at pH 6 and pH 7.5 conditions of the tergotometer trials. However, at pH 9 condition, the Y values of both the knitted and woven fabric did not change significantly.
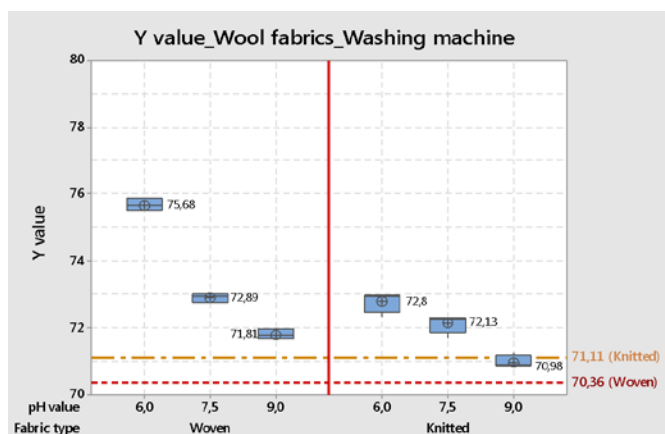
A.
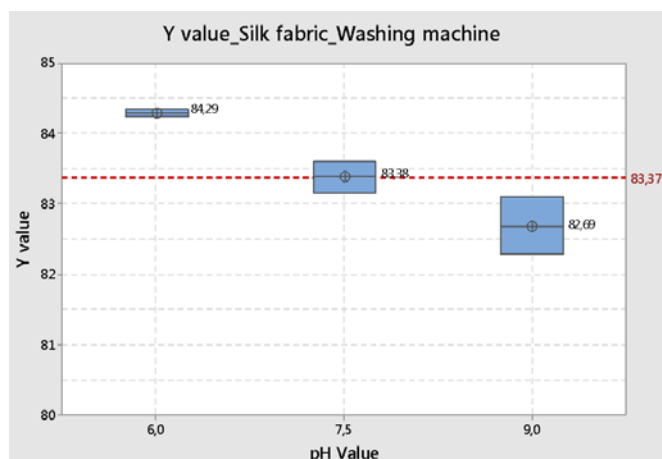
B.

Figure 9. Y Values of (a) woven and knitted wool fabric, (b) woven silk fabric after washing in domestic washing machine

Similar to the tergotometer test results, the Y values of the knitted and woven wool fabrics for domestic washing machine tests increased at pH 6 and pH 7.5 conditions. Moreover, for both knitted and woven fabrics, no specific change was observed at pH 9 condition.

The Y values of the silk sample were similar for all of the tergotometer and domestic washing machine trials. Irrespective of the washing device used (i.e., tergotometer and washing machine), the color change measurements had a similar tendency for the knitted and woven samples at the end of the fifth washing cycle (see Figure 9).

4. Conclusions

The study under discussion was conducted to systematically examine the influence of water pH, together with the other washing parameters, on delicate textiles' wear such as the ones from silk and wool. The most important results of the work can be given as follows:

1. Irrespective of the sample type, the number of washing cycle is the main effective parameter for dimensional change and bursting strength performance of delicate textiles.

2. In the case of dimensional stability performance of the samples, it is observed that the effect of pH value becomes more significant as the number of washing cycles is increased.

3. So far, as the knitted fabric samples are concerned, the water pH value is one of the most important parameters on bursting strength performance such that the lower the water pH value, the lower is the performance loss is observed. Moreover, its effect becomes more prominent as the number of washing cycles as well as water temperature are increased.

4. When it comes to washing performance, the protein-based stains such as blood and chocolate milk perform worse at a water pH value of 6, in comparison to their performance at a water pH value of 7.5. The non-protein-based stains, however, are not influenced by the change of the water pH value.

5. Water pH value affects color change, though further work is needed to analyze the interaction mechanism.

6. Tergotometer and domestic washing machine test results suggest a strong and positive correlation in terms of the dimensional change, tear strength, and bursting strength measurements.

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