DEU FMD 27(79) (2025) 31-37

Dokuz Eylül Üniversitesi Mühendislik Fakültesi Fen ve Mühendislik Dergisi
Dokuz Eylul University Faculty of Engineering Journal of Science and Engineering
Elektronik/Online ISSN: 2547-958X

RESEARCH ARTICLE / ARAŞTIRMA MAKALESI

Evaluation of Sustainable Washing Processes for Fashionable Effects in Denim

Denimde Moda Efektler için Sürdürülebilir Yıkama Proseslerinin Değerlendirilmesi

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Abstract

Sustainability has become an important issue in every sector today. Effective use of resources is an issue that needs to be emphasized at the global level. Since denim washing processes consume a lot of water, energy, chemicals and time, sustainable processes in this area have gained importance. Various denim washing processes developed in terms of effective use of resources for sustainable methods are applied. Practices may be aimed at reducing water consumption, or may be related to more sustainable chemical consumption. In addition, situations where the process is shortened, waste is reduced or water free processes can come to the fore can also contribute to sustainability. The effects of sustainable processes on fabric properties should also be considered. In this study, denim fabrics with fashionable fading and bleaching effects by different methods were used. Abrasion resistance and bending rigidity properties of denim fabrics with effects obtained by conventional and sustainable methods were investigated comparatively. The results obtained show that among the sustainable processes in the study, there are preferable processes in terms of bending rigidty and abrasion resistance properties.

Keywords: *Denim Fabric, Denim Washing Processes, Sustainability, Bending Rigidity, Abrasion*

Öz

Sürdürülebilirlik konusu günümüzde her sektörde önemli bir hal almıştır. Kaynakların etkin kullanımı global düzeyde üzerinde durulması gereken bir konudur. Denim yıkama işlemleri de çok fazla su, enerji, kimyasal ve zaman tüketimine neden olan süreçler olduğu için, bu alanda da sürdürülebilir uygulamalar oldukça önem kazanmıştır. Sürdürülebilir yöntemler için, kaynakların etkin kullanımı açısından geliştirilen çeşitli denim yıkama işlemleri uygulanmaktadır. Uygulamalar, su tüketimini azaltmaya yönelik olabileceği gibi, daha sürdürülebilir kimyasal madde tüketimiyle de ilgili olabilir. Ayrıca, sürecin kısaltıldığı, atıkların azaltıldığı veya kuru işlemlerin ön plana çıkabileceği durumlar da sürdürülebilirliğe katkı sağlayabilir. Sürdürülebilir proseslerin kumaş özellikleri üzerindeki etkileri de dikkate alınmalıdır. Bu çalışmada, farklı yöntemlerle elde edilmiş olan ve denimde moda olan eskitme ve ağartma efektlerine sahip denim kumaşlar kullanılmıştır. Konvansiyonel yöntemlerle ve sürdürülebilir yöntemlerle elde edilmiş efektli denim kumaşların aşınma dayanımı ve eğilme rijitliği özellikleri karşılaştırmalı olarak incelenmiştir. Elde edilen sonuçlar, çalışmadaki sürdürülebilir prosesler arasında eğilme rijitliği ve aşınma direnci özellikleri bakımından tercih edilebilir süreçlerin bulunduğunu göstermiştir.

Anahtar Kelimeler: *Denim Kumaş, Denim Yıkama Prosesleri, Sürdürülebilirlik, Eğilme Rijitliği, Aşınma*

1. Introduction

Sustainability is an issue of global importance today, and in this context, the effective use of resources is a factor that needs attention in the industrial sense. In terms of sustainability, the textile industry takes many measures to reduce the consumption in the processes. In this context, since denim washing processes consume a lot of water, energy, chemicals and time, the search for sustainable solutions in this regard has gained great importance.

In denim sector, there are fading and bleaching processes that have developed depending on fashion and have been applied for many years. There are dry fading processes such as sand blasting [1], whisker [2], hand sand [3], grinding [3] in denim. Laser process has created an alternative to these processes as a sustainable solution [4]. In addition to the dry fading processes in denim, there are also washing processes for the fading and bleaching effects. Pumice stone washing is one of these methods. [5]. This method is one of the conventional methods that has been used for many years. The pumice stone washing process creates a very good worn look effect or fading effect, but the necessity of unloading the stones from machines after the process, the need to the separation of stones and fabric from each other, damage of the stones to the machine over time, the environmental impact of the process are some of the disadvantages of this method. This is not an environmentally friendly process, and the process creates waste in the form of sludge. In addition, wastewater treatment becomes necessity. Some studies on the environmental effetcs of stone washing have been examined [6, 7]. Sustainable solutions such as the use of artificial stones [8], enzyme washing [9, 10], enzyme and stone washing [11] are applied as an alternative to stone washing. For bleaching of denim, denim fabrics are treated with Sodium Hypochlorite [12], Potassium Permanganate [13, 14], Hydrogen Peroxide [15]. Enzyme bleaching [16] and ozone technique processes [17, 18] are sustainable alternatives to

DOI: https://doi.org/10.21205/deufmd.2025277905

Geliş Tarihi / Received: 16.10.2023
Kabul Tarihi / Accepted: 26.03.2024

conventional bleaching processes. Plasma [19, 20] and water jet techniques [4, 21] are also sustainable methods for denim fading.

As sustainability gains importance, various studies examining alternative washing processes in denim appear in literature [7, 22, 23, 24]. In these studies, fabric properties such as tensile strength and color difference [7], tear strength and energy use [22], abrasion resistance and fastness to laundering [23] were examined. In this study, alternative washing processes of denim fabrics were studied. Both conventional and sustainable fading and bleaching processes have been applied to denim fabrics. The effects of sustainably advantageous processes in terms of various fabric performances were investigated. The main aim of the study is determining of abrasion and bending properties of denim fabrics subjected to conventional and sustainable denim fading and bleaching processes. Abrasion and bending properties are two important features for denim fabrics, and in this sense, the results of sustainable processes in terms of these properties are important.

2. Materials and Methods

2.1. Material

Table 1, which includes the properties of the denim fabrics used, is given below.

Table 1. Properties of the denim fabric.

Weaving structure	Weight in grams per square meter (g/m^2)	Raw material	Denim dyeing
Twill (3/1 Z)	480	Cotton	Indigo dyed

Weft yarn count of denim fabrics is Ne 8/1 Open-End and warp yarn count is 6/1 Open-End. Weft density is 18/cm and warp density is 20/cm.

2.2. Method

After weaving of the denim fabrics, they were pre-washed at 50°C for 10 minutes with a dispersing agent made of recycled PET and then the denim fabrics were desized. Then, fading and bleaching effect processes were performed and then test processes were carried out.

2.2.1.Fading and bleaching processes of denim fabrics

After pre-washing and desizing, the fabrics were subjected to fading or bleaching process with 6 different processes. Two of these processes (pumice stone and potassium permanganate spray processes) are conventional methods, while the others are sustainable processes.

Pumice stone washing process is made for fading effect of denim fabrics and this method is a conventional method. Pumice stone is not ecological and it is difficult to dispose of the waste generated by the process. As an alternative to this method, by using stone enzyme (SWE), a fading effect similar to that of pumice stone was obtained, and with this process, the waste in the form of sludge of the pumice stone was eliminated. Because this enzyme dissolves in water, no waste in the form of sludge is formed. As another method, a similar fading effect was obtained in an industrial washing machine using a chemical called ECHO WHITES, with a waterless process. The wet fabric that comes out of the pre-wash is treated with chemicals in the machine without using extra water. The process, which is carried out using ECHO WHITES chemical, is a sustainable method without water and provides an effect similar to the pumice stone fading effect.

The other three methods were applied for bleaching denim fabrics. The first method is the application of potassium permanganate (PP) spray, and a local bleaching is created on the fabric. It is a conventional method and there is a lot of water consumption, it is harmful to health, it has a toxic effect and it is not ecological. The process with chemical substance named PMN/PMK (chemical substitute for PP, PMN main chemical, PMK catalyst) is a locally effective spray application, which is both healthier environmentally friendly product and reduces water consumption by approximately 1/10. The use of this chemical also reduces processing time and this is important in terms of sustainability. Another process with water consumption as low as 1/10, PMN nebulisation, is a water free process. Denim fabric is treated with chemicals in a nebulisation system with nozzles. Denim fabric is bleached by spraying chemical from nozzles.

As can be seen, for fading or bleaching of denim fabrics, sustainable substitutes for conventional methods have been tried both by using stone enzyme or environmentally friendly chemical substance and by reducing or eliminating water consumption. The main purpose of this study is to analyze the results of these sustainable practices in terms of abrasion and bending characteristics, which are of great importance in denim.

Processes and their conditions applied to denim fabrics are given in Table 2.

Table 2. Processes and conditions applied to denim fabrics.

Process	Time *(min.)*	Temperature *(°C)*	Liquor ratio
Pumice Stone	30	50	1/5
SWE (Stone enzyme)	45	50	2 gr/l SWE
ECHO WHITES	30	Water free	%2 ECHO WHITES
PMN Nebulisation	20	Water free	%25
PMN/PMK Spray	-	Water free	%25
PP Spray	-	Water free	%5

After the PP spray process, neutralization is done with sodium metabisulfite for 5 minutes at 50 °C, and the excess PP is removed. Afterwards, the denim fabrics are washed with detergent at 50 °C for 5 minutes and dried at 75-80 °C. Detergent washing and drying is carried out under the same conditions after pumice stone washing, SWE washing, ECHO WHITES washing. After PMN/PMK spray and PMN nebulisation, drying process takes place, then the denim fabrics are washed with detergent and dried once more.

2.2.2.Test procedures of denim fabrics

Following the fading processes, the denim fabrics were exposed to abrasion resistance and bending rigidity tests. Test procedures conducted to denim fabrics are presented Table 3. Before test procedure, the samples were conditioned for 24 h in standard atmospheric conditions (temperature 20 ± 2 °C and relative humidity 65 ± 4%).

Table 3. Test procedures.

Test	Standard	Equipment	Repetition
Abrasion Resistance	TS EN ISO 12947-3 [25]	MESDAN	3
Bending Rigidity	TS 1409 [26]	Test device designed in accordance with the bending rigidity test standard	5

Abrasion behaviors of the denim fabrics were determined by measuring the mass loss amounts of the fabrics after abrasion cycles. Four levels of abrasion cycles 5.000, 10.000, 15.000 and 20.000 were applied to the denim fabrics with 12 kPa weight. Differences in mass loss after 5.000, 10.000, 15.000 and 20.000 abrasion cycles were determined by using fabric weight values before and after abrasion cycles.

On the other hand, the denim fabrics were subjected to bending rigidity test for determining of bending behavior of the denim fabrics in weft and warp direction according to TS 1409 and the formula for calculating bending rigidity with the values obtained in the bending rigidity test is given below.

$$G = 0{,}1\, W\, C^3\ mg.cm \quad (1)$$

Where,

X=Falling length (cm)

C=X/2 =Bending length (cm)

W=Fabric mass per unit area (g/m^2)

G=Bending rigidity (mg.cm)

Figure 1 shows denim fabrics with their effects after the processes and fabric samples appearances after the abrasion resistance test. Figure 2 shows the microscopic views at 30x magnification of denim fabrics before and after abrasion resistance test. While Figure 1 shows the color changes of denim fabrics after the abrasion resistance test, Figure 2 shows in detail the appearance of the weft and warp yarns on the worn test samples after the test.

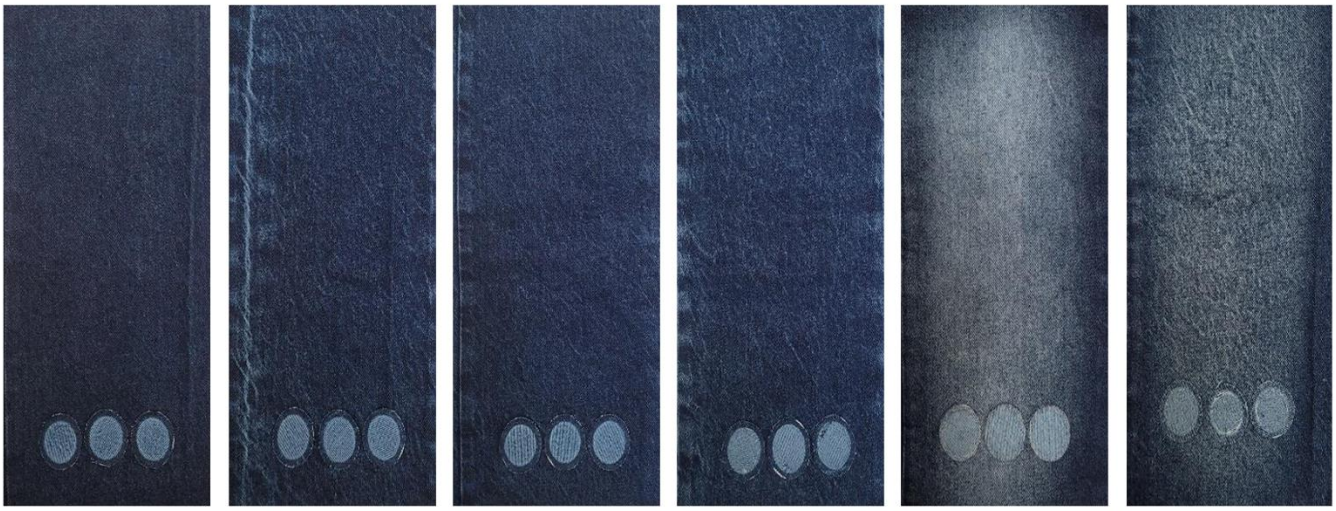

Figure 1. Effects after the processes on denim fabrics and fabric samples appearances after abrasion resistance test.

2.2.3.Statistical Analysis

After the test procedures, the findings were statistically evaluated at 95% confidence level via SPSS program (α=0.05).

3. Results

3.1. Bending Rigidity Test Results

Mass per unit area values of fabrics after processes and bending rigidity test results are given in Table 4.

Mass per unit area values and bending rigidity values in weft and warp direction are shown visually in Figure 3, Figure 4 and Figure 5, respectively.

As seen in Figure 3, the least mass loss was observed after the pumice stone process. It has been observed that the mass loss in fabrics with ECHO WHITES, SWE, PMN nebulisation and PP Spray is close to each other. It was observed after the processes that the highest mass loss is in the fabric to which PMN/PMK Spray is applied.

Table 4. Mass per unit area values of fabrics after processes and bending rigidity test results.

Processes	Mass per Unit Area *(g/m^2)*	Bending Rigidity in Weft Direction *(mg.cm)*	Bending Rigidity in Warp Direction *(mg.cm)*
Pumice Stone	425,89	623,48	745,56
ECHO WHITES	407,80	708,32	867,46
SWE (Stone enzyme)	408,21	651,24	730,21
PMN Nebulisation	413,29	755,19	839,70
PP Spray	412,62	709,86	730,23
PMN/PMK Spray	402,24	741,03	687,98

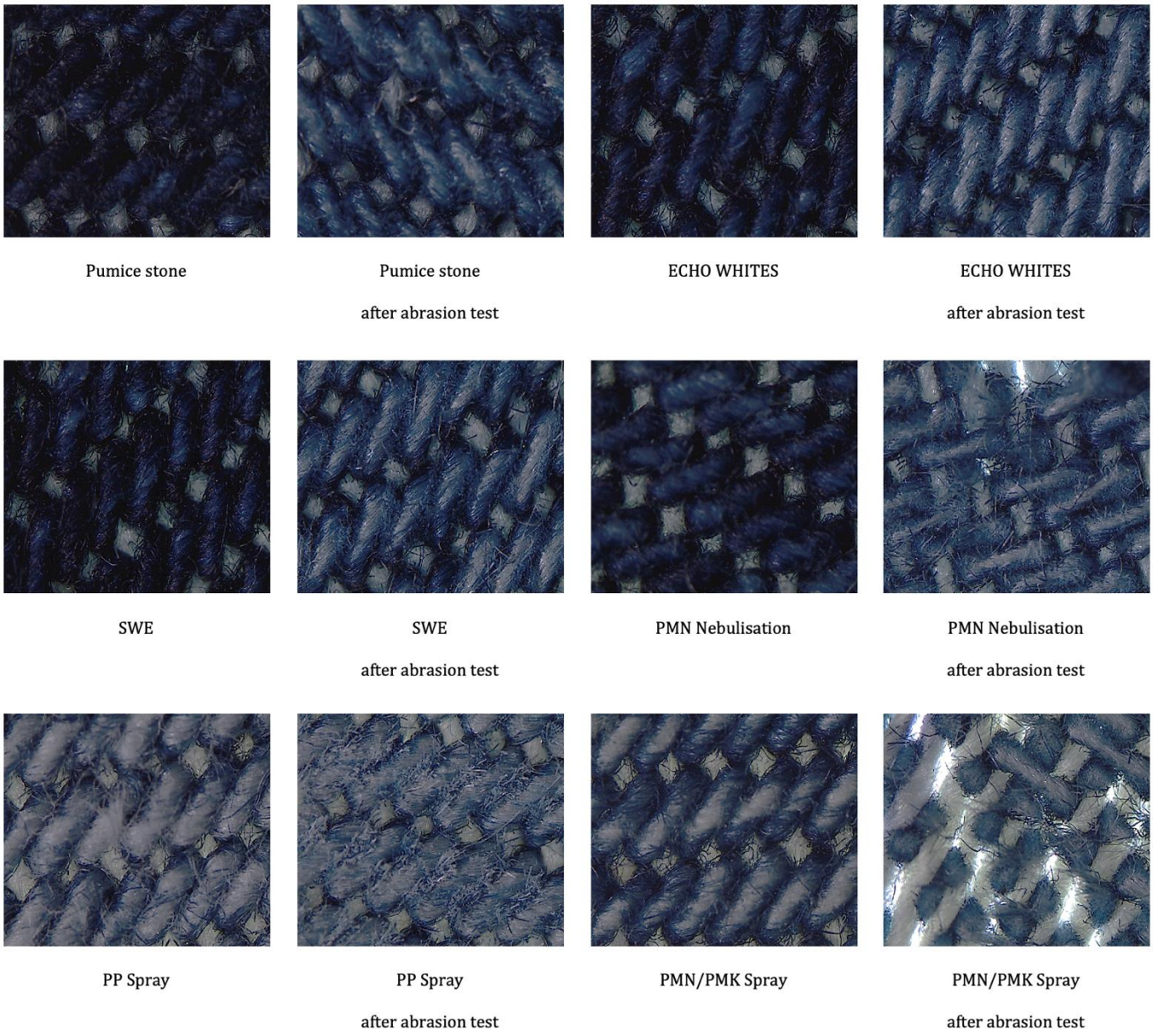

Figure 2. Microscopic views of denim fabrics before and after abrasion resistance test.

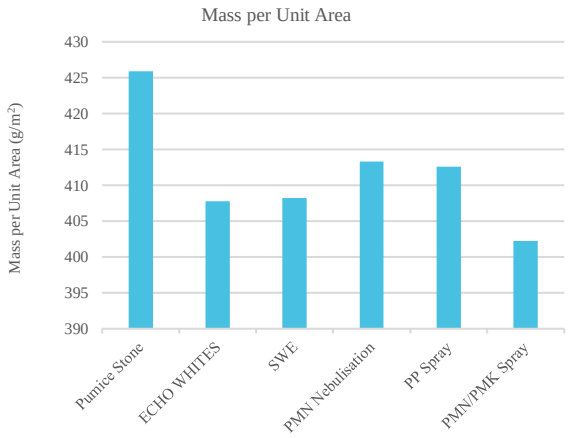

Figure 3. Mass per unit area values of fabrics after processes.

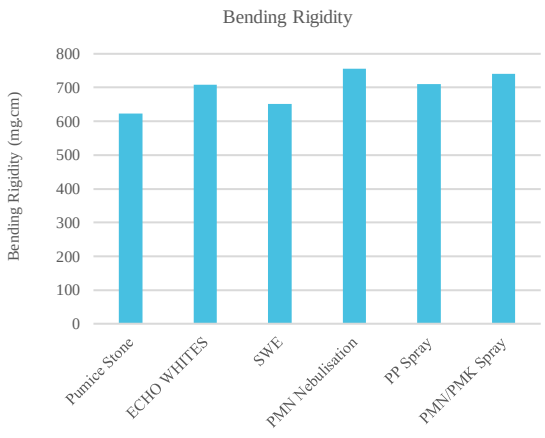

Figure 4. Bending rigidity test results in weft direction.

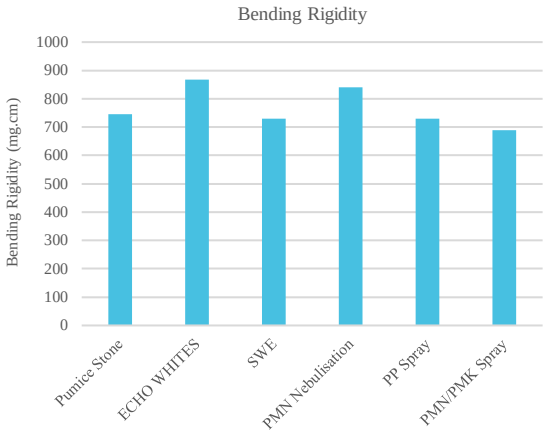

Figure 5. Bending rigidity test results in warp direction.

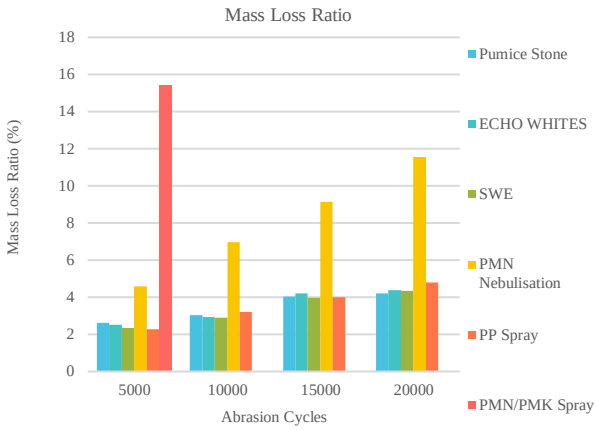

Figure 6. Mass loss ratio values of fabrics after abrasion resistance test.

As seen in Figure 4 and Figure 5, it was determined that the bending rigidity values in the warp direction were slightly higher than in the weft direction. On the other hand, the highest bending rigidity value in weft direction was seen after PMN nebulisation process and this value was followed by PMN/PMK Spray and ECHO WHITES process. The highest bending rigidity value was seen after ECHO WHITES process in warp direction. It was observed that this value was followed by the PMN nebulisation process in warp direction. Also the bending rigidity values of denim fabrics treated with Pumice Stone, SWE and PP Spray were close to each other in both weft and warp direction. In addition, the bending rigidity value of the fabric with PMN/PMK Spray was the lowest value among the fabrics in warp direction. Looking at the statistical evaluation, washing processes and fabric direction have statistically significant effect on bending rigidity (Table 6 and Table 7).

3.2. Abrasion Resistance Test Results

Mass loss ratio values of fabrics after abrasion resistance test are given in Table 5 and mass loss ratio values are shown visually in Figure 6.

Table 5. Mass loss ratio values of fabrics after abrasion resistance test.

	Mass Loss Ratio (%)			
Processes	**5.000 cycles**	**10.000 cycles**	**15.000 cycles**	**20.000 cycles**
Pumice Stone	2,61	3,04	4,05	4,22
ECHO WHITES	2,53	2,94	4,21	4,38
SWE (Stone enzyme)	2,33	2,89	3,96	4,34
PMN Nebulisation	4,57	6,96	9,15	11,55
PP Spray	2,27	3,21	3,99	4,81
PMN/PMK Spray	15,46	-	-	-

As seen in Figure 6, the mass loss ratio values of SWE, ECHO WHITES and PP Spray processes were close to those of the pumice stone process. Therefore, it would be appropriate to prefer the sustainable SWE and ECHO WHITES processes among these processes.

On the other hand, the mass loss ratio value of the PMN nebulisation process is high, but it does not suffer any degradation until 20000 cycles. When the fabric treated with PMN/PMK Spray was examined at 5000 cycles at abrasion test, it was seen that the sample disintegrated and the test was terminated. The disintegration can also be observed in microscopic views in Figure 2. Besides, in the mass measurements after the processes, the highest mass loss ratio value was observed in this fabric (Figure 3). Statistical analysis show that there is a statistically significant difference for the mass loss ratios after abrasion resistance test according to washing processes and level of abrasion cycles (Table 6).

Table 6. The one-way analysis of variance table for the results.

Property	**Factor**	**F**	**p-values**
Mass loss ratio after abrasion resistance test	Washing processes	23,785	0,000*
	Level of abrasion cycles	6,250	0,001*
Bending rigidity	Washing processes	4,578	0,001*

*: Statistically significant for α=0.05.

Table 7. Independent samples T-Test results for the values.

		Levene's Test for Equality of Variances		**t-test for Equality of Means**
		F	**Sig.**	**Sig. (2-tailed)**
Property	**Factor**			
Bending rigidity	Fabric direction	1,342	0,252	0,001*

*: Statistically significant for α=0.05.

Besides, results of multiple comparisons of washing methods show that significant difference occur only in PMN Nebulisation from other washing methods. In addition, when the statistical analysis was examined in two groups as conventional and sustainable washing methods, it was observed that the difference between the methods was also found to be statistically significant. PMN/PMK Spray method was not included in the statistical analysis of abrasion property because abrasion test of this method was not completed.

4. Conclusion and Discussion

In this study, conventional and sustainable fading and bleaching processes were applied on the denim fabrics to examine sustainable processes in denim washing. Besides the sustainable properties of these processes, it is aimed to determine the abrasion and bending performances of the denim fabrics subjected to these processes. In this context, abrasion resistance and bending rigidity tests were applied to denim fabrics.

According to the findings; bending rigidity values show that the effect of stone enzyme process SWE on fabric bending rigidity is similar to pumice stone, and in a sustainable sense, it can be said that stone enzyme process can be preferred in terms of bending rigidity. It can be stated that the bending rigidity values of ECHO WHITES and PMN nebulisation processes are slightly high, but they are at a usable level. Therefore, it can be said that these processes will not pose a problem in terms of bending rigidity when used in a sustainable manner. When we look at the two spraying processes that have local bleaching properties, it was observed that the bending rigidity value of the PMN/PMK Spray process, which stands out as sustainable, was lower than the PP Spray process. Otherwise it was observed that the denim fabric treated with PMN/PMK Spray process disintegrated after 5000 cycles at abrasion test. Therefore, it is recommended to try this process under different conditions such as lower chemical substance intensity, shorter spray process time, lower drying temperature and shorter drying process time. In addition, abrasion resistance test show that the mass loss ratio values of SWE, ECHO WHITES and PP Spray processes were close to those of the pumice stone process but while that of PMN nebulisation process is higher. It can be said that the obtained bending and abrasion results depend on the methods and conditions of the applied processes, as well as the chemicals or materials used. Looking at all these comments, considering both bending rigidity and abrasion resistance properties, it can be stated that SWE process, which is one of the sustainable process among these processes with stone enzyme, is the optimum option with similar values to pumice stone. In addition, it seems that ECHO WHITES process also is preferable. PMN nebulisation process may also be preferred, considering that abrasion values are higher.

Since there is a lot of water and chemical consumption in denim washing processes, sustainability studies on this subject are of great importance. As examined in this study, if it provides fabric properties at acceptable levels, the use of sustainable methods that do not produce waste in the form of sludge, minimize water use, also enable water-free processes and increase the use of more environmentally friendly chemicals, should be supported.

For future studies, sustainable processes in denim fabrics with different properties can be tested for different fabric properties. As an alternative to conventional materials, artificial stones and recycled materials can be used for more sustainable processes. For a denim fabric with optimum properties, sustainable processes with less resource consumption can be determined.

Ethics committee approval and conflict of interest statement

Ethics committee approval is not required for this article. There is no conflict of interest with any person/institution in this study.

Acknowledgement

The author thanks to Dr. Ümit CIKCIK, Ahmet Bülbül and ARM Tekstil Boya Kimya San. ve Tic. Ltd. Şti. for supplying denim fabrics.

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