Araştırma Makalesi / Research Article

A COMPARATIVE STUDY ON SUSTAINABLE OZONE TREATED AND TRADITIONALLY WASHED DENIM FABRICS WITH SELECTED PROPERTIES

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***ABSTRACT*:** Denim fabrics are one of the most widely used textiles in garment industry due their durable structure and potential of having stylish look via washing processes. Besides traditional methods of denim washing, novel techniques have a great attention as well considering sustainability, time and cost effectiveness. In the present study sodium hypochlorite bleaching and ozone bleaching in differing treatment time and chemical concentration parameters were applied to the denim fabrics. Then the fabrics were conducted to air permeability, tensile strength and elongation, abrasion resistance, bending rigidity, fastness to rubbing and fastness to washing tests via standard methods. Hence, fade effects of the processes on the fabrics and their performance properties were evaluated comparatively through statistical analysis. It was concluded that ozone treatment as an eco-friendly process provided superior results in suitable conditions while not causing a major disadvantage compared to the traditional bleaching of denim fabrics. Especially wet ozone treated fabrics were found to be substitute to NaOCl treated ones in terms of the investigated properties and fading effect evaluations under suitable treatment time and concentration levels.

Keywords: Denim fabric, Ozone bleaching, Hypochlorite bleaching, Sustainability, Mechanical properties

SÜRDÜRÜLEBİLİR OZON İŞLEMİ UYGULANMIŞ VE GELENEKSEL OLARAK YIKANMIŞ DENİM KUMAŞLARDA SEÇİLMİŞ ÖZELLİKLER İLE KARŞILAŞTIRMALI BİR ÇALIŞMA

***ÖZ*:** Denim kumaşlar, dayanıklı yapıları ve yıkama işlemleriyle şık bir görünüme kavuşma potansiyelleri nedeniyle hazır giyim sektöründe en çok kullanılan tekstil ürünlerinden biridir. Geleneksel denim yıkama yöntemlerinin yanı sıra, sürdürülebilirlik, zaman ve maliyet etkinliği göz önünde bulundurularak yeni teknikler de büyük ilgi görmektedir. Bu çalışmada, farklı işlem süreleri ve kimyasal içerik parametrelerinde sodyum hipoklorit ağartma ve ozon ağartma denim kumaşlara uygulanmıştır. Daha sonra kumaşlara standart yöntemler kullanılarak hava geçirgenliği, kopma mukavemeti, uzama ve aşınma direnci, eğilme rijitliği, sürtme ve yıkama haslığı testleri uygulanmıştır. Böylelikle, işlemlerin kumaşlar üzerindeki solma etkileri ve performans özellikleri istatistiksel analiz yoluyla karşılaştırmalı olarak değerlendirilmiştir. Çevre dostu olan ozon işleminin, denim kumaşların geleneksel ağartılmasına kıyasla büyük bir dezavantaja neden olmadan, uygun koşullarda üstün sonuçlar sağlayabileceği sonucuna varılmıştır. Özellikle uygun süre ve konsantrasyonda yaş ozon işlemine tabi tutulmuş kumaşlar incelenen özellikler ve solma efekti bakımından NaOCl ile işlem görmüş kumaşlara ikame olacak nitelikte bulunmuştur.

Anahtar Kelimeler: Denim kumaş, Ozon ağartma, Hipoklorit ağartma, Sürdürülebilirlik, Mekanik özellikler

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1. INTRODUCTION

Denim has been one of the most commonly preferred fabrics in textile and apparel industry. Regardless of age, gender identitiy and seasonal conditions people use denim products in the perception of timeless fashion [1-3]. Thanks to it's durable structure it enables to apply different finishing treatments that enhances softness, comfort and fading effects meeting the demand from customers within a higher satisfaction concept. Hereby denim washing is considered as the most critical and dramatically changing process among the finishing treatments that provides the desirable change in texture, comfort properties and stylish look of the fabrics [4-7].

Washing techniques can be mainly divided into 3 groups; biological washing in which enzymes are used as the main actors. Wet/chemical washing includes mainly rinse washing, pigment washing, caustic washing, silicon washing, acid washing and bleach washing. Dry/mechanical washing is applied to maintain scraping, spraying, whiskering, dots, rubbing, and tacking on denim products [1, 8-10]. The major outcome from these techniques are familiar such as avoiding undesired materials like dirt and dust or sizing materials on the fabric. Softening the fabric and achieving a good texture are the most commonly desired outcomes as well. Essentially a cycle of wet and dry processes as a combination is followed in the washing processes to create various effects on the denim fabrics to fullfill the requirements of the customers. In terms of both technical and visual aspects denim washing has been the major neccessity along with the evolution of denim garment production.

Among washing techniques, bleaching plays a major role on the color perception and vintage look via giving distinctive color fading effects. Bleaching is essentially a mechanism of decolorization through oxidation in which oxidizing agents such as sodium hypochlorite, potassium permanganate, hydrogen peroxide etc. are used. Althouh these conventional processes have been widely used in denim garment industry due to their efficiency, they are considered as harsh chemicals and they generate huge amounts of polluted effluents. In alignment with sustainability concerns, arising from an increasing social conciousness through environmental and economical aspects, novel technologies with sustainable approachments are in use since last decade [11-14].

Concerning the benefits of reducing chemicals on health issues, water consumption and time effectiveness of the process, ozone treatment has been attracting great attention from both producers and researchers. Within this concern, Shibly et al. studied on the usage of natural sources such as lemon, ginger and pomelo as color changing materials on denim fabrics instead of chemical agents. They carried out tensile strength and air permeability tests besides color difference and surface characterization tests. It was reported by the researchers that the natural fading techniques can be applied on indigo dyed denim fabrics succesfully [15]. Islam et al. carried out a comprehensive study on washing types in denim fabrics namely enzyme wash, acid wash and bleach wash in traditional techniques. The researchers found out that application of ozone treatment as well, reduced enzyme wash duration, chemical concentration and also provided bleaching effect. They carried out environmental impact measurement tests. Instead of conventional chemicals such as sodium hypochlorite and potassium per manganate ozone was reported as an applicable eco friendly process for bleaching [16]. Hamida and Ladhari, examined the influence of the parameters such as ozone concentration, moisture content and time of exposure to ozone on denim fabrics. They reported that wet ozone treatment was more profitable and maintains a wider range of washed look than dry ozone. Providing the same wet processing conditions was found to be important to avoid an uneven bleaching. The reaserchers additionally investigated the tensile strength and rubbing fastness of the fabrics. Duration of the treatment and ozone concentration were the main actors affecting the strength of the fabrics. On the other side, dry rubbing results were better than wet ones [17]. Hamida et al. in another study, investigated application of ozone in combination with ultrasound technique and hydrogene peroxide on denim fabrics for bleaching. Surface morphology, tensile strength and fastness tests were performed. It was observed that moderated concentration of ozone caused no harm on the fabrics with maintaing a satisfactory bleaching [18]. Atav et al. emphasized benefits of ozone treatment over traditional denim washing techniques in their study. They examined the effects of parameters such as; water content, treatment time and pH on both color fading and strength of the denim fabrics during ozone treatment. In need of optimization of the procedure they observed that the water content of the fabric and pH plays a significant role to obtain the best color fading effect with minimum loss in fabric strength, on the other hand duration of the treatment should be determined concerning the desired color fading level [19]. Nadeem et al. studied with six different denim fabrics processing thorugh ozone in air combination with aerosol spray technology for their fading look. The samples treated with ozone and sodium hypochlorite were undergone a comprehensive testing procedure including air permeability, water vapour permeability, thermal characteristics and KES-F to determine the mechanical and surface characteristic. It was reported that ozone treatment was as efficient as conventional bleaching but with better retention of mechanical and comfort properties. Besides, process time and moisture pick up management were found to be the major actors to have a uniform bleaching [20]. Benli and Bahtiyari carried out a compreative stduy to determine the effect of traditional washing methods and ecologically benign methods such as ozone and ultrasound treatment on cotton fabrics. They observed ozone–ultrasound combination applied fabrics demonstrated an approximate hydrophilicity and whiteness value obtained using the traditional technique. They additionally reported that ozone-ultrasound combination can be used for the pretreatment of cotton as a support for sustainable applications [21]. Nizam et al. used denim fabrics containing polyester and elastane in their study. They applied random wash including stone enzyme and acid wash to the denim fabrics. By the end of random washing they treated the fabrics with ozone to examine the color fading effect. Considering the fiber composition of the fabrics it was revealed that ozone treatment was majorly affected by cotton, followed by polyester, and finally elastane. In the most cotton containing fabric with a higher polyester content than elastane, ozone was the most effective finishing agent. They also made evaluations on tensile strength, tear strength, color fastness to ozone and color fastness to crocking of the denim fabrics [22]. Fraj and Jaouachi, studied denim fabrics with the components of cotton, polyester and elastane fiber in different blend ratios. They investigated the influence of ozone treatment on the appearance and physical characteristics of the fabrics. For this purpose, bagging resistance, tensile strength, shrinkage, spectroscopy and rubbing fastness tests were conducted to the denim fabrics. In conclusion they reported that ozone treatment had a significant effect on the mechanical and color features of denim. To fullfill the sustainable approach as well as the requirements of the customers denim should be treated with a moderate concentration of ozone for a short time [23]. Yiğit et. al., studied on dyed cotton fabrics in colors of red, yellow, blue and black. They aimed to get color fading through sodium hypochlorite and ozone treatments on these denim fabrics. For this purpose they investigated color changes and surface morphology as well as some other mechanical properties after treatment processes. It was observed by the authors that both processes worked well by means of strength and surface characterization. Additionally, as an environmetally benign method ozoneation was found to be effective in color degradation [24]. Kamppuri and Mahmood, investigated color change and back staining of denim fabrics dyed with indigo, mixture of indigo and sulphur dyestuff. These fabrics were treated with ozone in wet medium. It was revealed that ozone treatment was capable of decreasing the backstaining and bleaching effect was promisingly uniform without a significant strength loss of the fabrics [25]. Apart from studies on denim fabrics, researchers have investigated the effect of ozone treatment as bleaching agent in comraison with conventional hydrogen peroxide belaching on cellulosic fabrics (mainly cotton) in different circumstances. Walawska et. al., studied on 100% cotton woven fabric in their investigation hence cellulose materials were bleached using hydrogen peroxide. The researchers stated that gas-phase bleaching procedures, due to the lower temperature and minimal water consumption, have economic and environmental advantages, in comparison with conventional methods [26]. Eren and Yetişir, examined bleaching of cotton using ozone treatment, compared to conventional hydrogen peroxide bleaching. They revealed that in terms of color analysis, ozone decreases the yellowness on the fabric and helped to remove sizing agents from the fabric [27]. In another study on cotton fabrics, Perinçek et. al., applied ozone treatment on 100 % cotton fabric in different conditions and investigated optimization of ozone treatment through chemical and mechanical parameters.The researchers revealed that an acceptable level of whiteness can be achieved by ozone bleaching in a very short time, specifially for cotton products [28]. Palabıyık et. al. studied on hemp/cotton blended denim fabrics in terms of ozone fading methods. They observed that after washing processes, in comparison with raw denim, some mechanical properties such as air permeability and circular bending stifness. At the same time, the researchers stated that ozone washing system is a time, energy and water saving method compared to conventional washing methods [29]. Al et al., performed a study aiming to reduce the use of water and harsh chemicals in denim finishing. They applied ozone treatment in different circumstances to evaluate the determined performances of the fabrics. It was concluded that ozone treatment is a promising method in denim bleaching in terms of mechanical and color features [30].

Current research focuses on developing alternative denim finishing processes that prioritize environmental sustainability, time efficiency, and cost-effectiveness. In this context, ozone treatment either alone or combined with auxiliary agents, emerges as a prominent method. By optimizing parameters such as exposure time, ozone concentration, and process cycles, this technique yields results comparable to conventional washing. Ultimately, ozone treatment proves to be an ecologically benign alternative, significantly reducing water consumption, chemical usage, and energy requirements for both producers and consumers.

This study contributes to the literature by comparing dry and wet ozone treatments with conventional bleaching of denim fabrics, focusing on fading effects under compatible exposure times and concentrations. Based on industrial preliminary trials, process parameters were calibrated to achieve comparable fading levels across all methods. Furthermore, the experimental design was tailored to the most common application areas of denim. This approach enables a comprehensive investigation into the impact of these finishing processes on both aesthetic fading and critical performance criteria, such as mechanical durability and color fastness.

In this context, indigo dyed denim fabric in composition of 99%-1% cotton elastane was used to obtain sodium hypochlorite bleached, wet ozone and dry ozone treated samples in different chemical concentration levels and different time of exposure to the chemicals. Within the scope of this study, 13 fabric samples (including the control sample) were investigated to establish a basis for comparing fading outcomes. To assess the impact of the finishing processes, the samples underwent comprehensive testing for mechanical durability that of tensile strength and elongation, abrasion resistance and bending rigidity, air permeability, and color fastness. The experimental data were statistically analyzed to evaluate the influence of chemical concentration and exposure duration on the physical and chemical properties of the denim fabrics. Despite extensive research on ozone treatment in denim finishing, there is a notable gap in studies that simultaneously evaluate dry and wet ozone applications in comparison with conventional methods. To address this deficiency, the present study investigates both techniques under consistent conditions, aiming to provide a comprehensive comparative analysis that contributes to the existing literature.

2. MATERIALS AND METHODS

2.1. Material

The fabric used in the tests has the following characteristics: composition: 99% cotton (cellulosic fiber), %1 elasthane, weave: 3/1 Z twill, weight: 393 g/m^2, dye: blue indigo. Weft yarn count of denim fabrics is Ne 10,37 and warp yarn count is Ne 5,89. Weft density is 14/cm and warp density is 20/cm. The original denim fabric is illustrated show in Figure1.

Figure 1. Original Denim Fabric (F13)

2.2. Method

There are various industrial denim bleaching technologies including stone washing, micro sanding, denim bleaching, enzyme washing and acid washing. Before proceeding with the ozoneation process, the fabrics must undergo desizing treatment in order to guarantee the diffusion of ozone and water into the fiber.

2.2.1. Pre-treatment applied to denim fabrics

In the pre-treatment, first rinse wash was applied followed by stone enzyme. Rinse wash process: It is the application of anti-cracking/wetting/enzymatic sizing/dispergator at 40^{0}C for 5 minutes. The additives used to ensure that the fabric has a certain softness and drapebility. In the stone enzyme process, 10 gr/lt is kept in the cold for 25 minutes in 100 liters. After pre-treatment, 3 different bleaching processes are applied to the fabrics. These processes are hypochlorite (NaOCl) bleaching, wet ozone and dry ozone processes. The effects of ozone on environment as well as on the garment are significant and cannot be neglected because number of benefits are achieved such as time saving, less energy consumption, chemical, labour cost reduction, less discharge of water and chemicals [31].

2.2.2. Main processes applied to denim fabrics

2.2.2.1 Bleaching Process with Dry Ozone

Bleaching of denim products with ozone can be defined as the oxidation of indigo dyestuff on the sample. The process was performed by means of an ozone machine G2 Plus from Jeanologia (Figure 2). Using air in the atmosphere, the ozone machine produces ozone by reacting with the dyes in the fabrics, giving the clothes the appearance that they have actually been desired to have. Additioanlly, it performs a zero-emission process, providing significant savings in water and chemicals, as well as great benefits such as cleaning every indigo residue and having a control on the the structure of the fabric.

Figure 2. Ozone machine Jeanologia G2 Plus [32]

After rinse washing process, denim fabrics were dried at 600^{0}C for 25 minutes at an adjusted humidity level of 12-13%. Then, dry ozone treatment was applied to fabrics numbered F1, F2, F3, F4. Process conditions and denim fabric codes are presented in the Table 1.

2.2.2.2 Bleaching Process with Hypochlorite

Samples numbered F5, F6, F7, F8 were processed with 1 lt NaOCl in 50 lt water at 50^{0}C. Fabric samples had a water content of 40-50% of their total fabric weight prior to this process. The fabric was sent for neutralization while wet. Neutralization: 3 gr/lt bisulphite was given in 100 lt water in cold for 3 min. Cold rinsing was done in 100 lt water for 2 min and 2 repetitions. Then bleaching process with NaOCl was applied to fabrics numbered F5, F6, F7, F8. Process conditions and denim fabric codes are given in the Table 2.

2.2.2.3 Bleaching Process with Wet Ozone

Fabric samples had a water content of 40-50% of their total fabric weight prior to wet ozone process. As a result of the oxidation of indigo dyestuff during the process, residual substances are formed. Due to these residue, the surface of the denim products turns to a yellow-green color which is known as yellowish problem. At this point, the color change problem was solved by applying 500C for 3 min to all wet ozoneated products and as a result of the removal of these by-products with the rinsing performed after the process, the yellowness on the product was removed [33]. Thus, the samples were given a uniform bleaching effect. Since indigo is a flowing dye, there is a backstainig problem as well. Through the processes performed, the desired color tone was achieved and backstainig was prevented. Ozone is as efficient as NaOCl and does not cause backstainig as a great advantage. Latter, wet ozone treatment was applied to fabrics numbered F9, F10, F11, F12. Process conditions and denim fabric codes are given in the Table 3.

During the determination of concentration levels and treatment durations under industrial operating conditions, preliminary trials were conducted in alignment with industrial references and the color profiles of fabrics bleached via traditional and sustainable methods. Consequently, while the bleaching durations for dry ozone and hypochlorite treatments were established as 5 and 10 minutes, respectively, a broader range of 5, 10, 12, and 17 minutes was applied for the wet ozoneation processes to optimize the production stages.

In this study, the denim fabric was treated through traditional bleaching method and ozone at different values of ozone concentration and time of exposure to ozone in both dry and wet conditions. Then some of the essential mechanical tests such as; air permeability, tensile strength, abrasion resistance, bending rigidity, color fastness to rubbing (dry and wet) and washing were performed in a comperative aspect between treated and non treated samples.

Table 1. Processes and conditions applied to denim fabrics

Code	Process	Time (min.)	Temperature (ºC)	Ozone concentration (%)
F1	DLCS	5	Room Temperature	10
F2	DLCL	10	Room Temperature	10
F3	DHCS	5	Room Temperature	30
F4	DHCL	10	Room Temperature	30

D: Dry Ozone Lc: Low Concentration Hc: High Concentration S: Short Time L: Long Time

Table 2. Processes and conditions applied to denim fabrics

Code	Process	Time (min.)	Temperature (ºC)	NaOCl (g/lt)
F5	HLCS	5	50	20
F6	HLCL	10	50	20
F7	HHCS	5	50	40
F8	HHCL	10	50	40

H: Hypochlorite Lc: Low Concentration Hc: High Concentration S: Short Time L: Long Time

Table 3. Processes and conditions applied to denim fabrics

Code	Process	Time (min.)	Temperature (ºC)	Ozone ratio(%)
F9	WLCS	12	Room Temperature	10
F10	WLCL	17	Room Temperature	10
F11	WHCS	5	Room Temperature	30
F12	WHCL	10	Room Temperature	30

W: Wet Ozone Lc: Low Concentration Hc: High Concentration S: Short Time L: Long Time

2.2.3 Test procedures of denim fabrics

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

The abrasion behavior of denim fabrics was determined by measuring the mass loss ratio of the fabrics after abrasion cycles. Four levels of abrasion cycles were applied to denim fabrics weighting 12 kPa: 5,000, 10,000, 15,000 and 20,000. Differences in mass loss ratio after 5,000, 10,000, 15,000 and 20,000 abrasion cycles were determined using fabric weight values before and after abrasion [34].

In order to determine the tensile strength behavior of denim fabrics in the warp and weft directions, the strip method was applied in the SDL Testometric M350 testing device in accordance with the TS EN ISO 13934-1 standard (5 kN constant elongation rate, distance between: 100 mm and speed: 100 mm/min. Pre-tension: 5 N) [35].

On the other hand, in order to determine the air permeability behavior of denim fabrics, TS 391 EN ISO 9237: 1999 standard was applied in the Textest FX 3300 Air permeability device. (Test Area: 20 cm^2, Test Pressure: 100 Pa) [36].

Furthermore, the bending behavior of the denim fabrics was evaluated in both weft and warp directions in accordance with the TS 1409 standard [37]. The bending rigidity was subsequently calculated using the following equation (1). Measurements were conducted through Shirley Bending Rigidity Testing Device.

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

X=Falling length (cm)
C=X/2 =Bending length (cm)
W=Fabric mass per unit area (g/m^2)
G=Bending rigidity (mg.cm)

Rubbing fastness is the resistance of a fabric to transfer the color of another fabric to it with a certain amount of contact. The Rubbing Color Fastness Test was performed according to the TS EN ISO 105-X12 standard, and both dry and wet rubbing fastnesses were examined [38]. With this test, using a device that applies a force of 9N, the staining/dyeing of standard white cotton fabrics was evaluated. With the gray scale, the lowest fastness value is assigned as "1" and the highest fastness value is assigned as "5".

Denim fabric products are frequently washed due to their wide range of uses. This highlights the importance of wash fastness. The Wash Fastness Color Test was conducted according to the TS EN ISO 105-C06 standard [39]. In the test, ECE (B) reference detergent containing phosphate and standard multifiber DW were used.

Table 4. Test procedures

Test	Standards	Repetition
Air permeability	ISO 9237	10
Tensile strength	TS EN ISO 13934-1	5
Abrasion Resistance	TS EN ISO 12947-3	3
Bending rigidity	TS 1409: 1973	5
Color fastness to rubbing	TS EN ISO 105 X12: 2016	
Color fastness to washing	TS EN ISO 105 C06: 2010	

2.2.4. Statistical Analysis

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

3. RESULTS AND DISCUSSION

Figure 3 shows the fading appearance of denim fabrics with the effects of the treatments. To evaluate the fading effect of the treatments, it was observed that dry ozone treated fabrics demonstrated insignifcant fading, considering time of exposure and ozone concentration in comparison with the original fabric. Whereas, wet ozone treatment made an observable effect on the colors of the fabrics in terms of the treatment circumstances. Additionally, as the time of exposure and concentration level of the treatment increased, fading effect was improved for wet ozone and NaOCl treatment. Besides, although the lightest colors were obtained at the NaOCl treated fabrics, it can be concluded that wet ozone treated fabrics can be used as a substitute for fading effects with NaOCl in appriopriate usage areas (Figure 3).

3.1 Air Permeability Results

Fabric air permeability values of all fabrics are given in Table 5 and visually in Figure 4.

Table 5. Air permeability and %CV values.

Fabric Code	Air Permeability	%CV
F1	35,58	4,70
F2	37,71	3,20
F3	36,88	4,00
F4	37,31	2,20
F5	32,40	1,80
F6	33,44	4,00
F7	34,25	2,10
F8	32,98	1,60
F9	34,22	3,70
F10	34,31	3,80
F11	34,46	1,40
F12	33,35	3,00
F13	63,15	5,20

As seen in Figure 4, the highest air permeability value was observed for original fabric with no treatment as expected. Considering the treated fabrics with NaOCl and ozone, it was seen that NaOCl treated fabrics had the lowest air permeability values in similar concentration and time in general compatible with literature [20]. It can be related to the fact that ozone treatment made no harmful effect on the cellulosic structure of the fabric, while NaOCl may have caused a distortion on the fibers or yarns in the fabric which decreases the volume of spaces [20]. Besides, the values were followed by wet ozone treated fabrics and the dry ozone treated fabrics had the highest air permeability values among treated fabrics.

The results in terms of treatment time on air permeability reflect that, air permeability values increased as the treatment time increased for the dry ozone treated fabrics. On the other hand, air permeability values did not demonstrate a regular change according to the treatment time for the NaOCl and wet ozone treatment. From the air permeabililty results on the basis of treatment concentration for both NaOCl treated and ozone treated fabrics, it is clear that while the increase in concentration in the short-term process increased the air permeability, the opposite was observed in the long-term process. It is understood from this result that the effect of treatment concentration on air permeability property varies depending on treatment time.

As can be seen in Tables 9 and Table 10, treatment type have a statistically significant effect on air permeability property.

			
F1- DLCS	**F2-DLCL**	**F3- DHCS**	**F4- DHCL**
			
F5-HLCS	**F6- HLCL**	**F7- HHCS**	**F8- HHCL**
			
F9-WLCS	**F10- WLCL**	**F11- WHCS**	**F12- WHCL**

Figure 3. Effects after the processes on denim fabrics

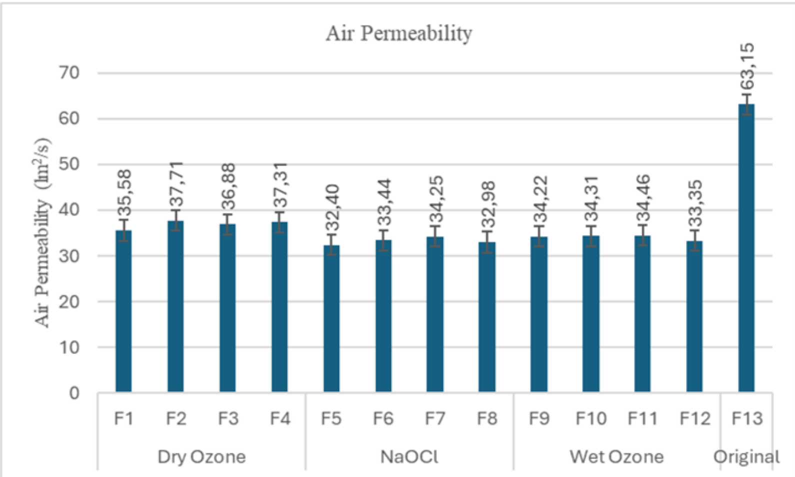

Figure 4. Air permeability values of fabrics

3.2 Abrasion Resistance Results

Mass loss ratio values of all fabrics after 5000, 10000, 15000 and 20000 abrasion cycles are given in Table 6 and the values are shown graphically in Figure 5.

As far as the mass loss ratio values are considered in terms of the ozone treatment, Figure 5 demonstrates that the values of dry ozone treated fabrics were lower than those of wet ozone treated fabrics in general.

It was observed that the mass loss ratio values were lower in NaOCl treated fabrics those of ozone treated fabrics for low concentration whereas there was no regular change for high concentration. For evaluation of the mass loss ratio values according to fabric type, among dry ozone treated fabrics, the lowest mass loss ratio values were observed in F3 fabric, and the highest in F4. Among NaOCl treated fabrics, the lowest values were observed in F5 fabric, and the highest in F8 fabric. Among wet ozone treated fabrics, the lowest values were observed in F12 fabric, and the highest mostly in F10 fabric. These results indicate that among dry ozone and NaOCl treated fabrics, mass loss ratio values increased with increasing treatment concentration in long-term processes. In wet ozone, mass loss ratio values were higher at low concentrations. Therefore, the effect of concentration was also affected by treatment type.

Table 6. Mass loss ratio values of fabrics

Fabric code	Number of cycles							
	5000	%CV	10000	%CV	15000	%CV	20000	%CV
F1	1,98	0,14	2,33	0,14	3,23	0,13	3,15	0,20
F2	1,84	0,43	2,11	0,50	2,85	0,52	2,76	0,51
F3	0,48	0,39	0,79	0,92	1,69	1,00	1,99	0,96
F4	1,94	0,44	2,61	0,50	3,46	0,58	3,85	0,60
F5	0,14	0,77	0,44	0,82	1,33	0,85	1,62	0,88
F6	1,66	0,75	1,98	0,71	2,27	0,73	2,59	0,69
F7	1,55	0,26	1,89	0,20	2,34	0,22	2,65	0,25
F8	1,60	0,30	2,04	0,27	2,54	0,19	2,84	0,23
F9	1,96	0,72	2,79	0,71	3,27	0,71	3,35	0,71
F10	1,90	0,18	2,79	0,17	3,28	0,15	3,51	0,20
F11	1,69	0,60	2,44	0,59	2,86	0,57	2,98	0,55
F12	1,67	0,71	2,05	0,70	2,73	0,73	2,77	0,83
F13	1,51	0,81	2,37	0,79	2,30	0,78	2,58	0,79

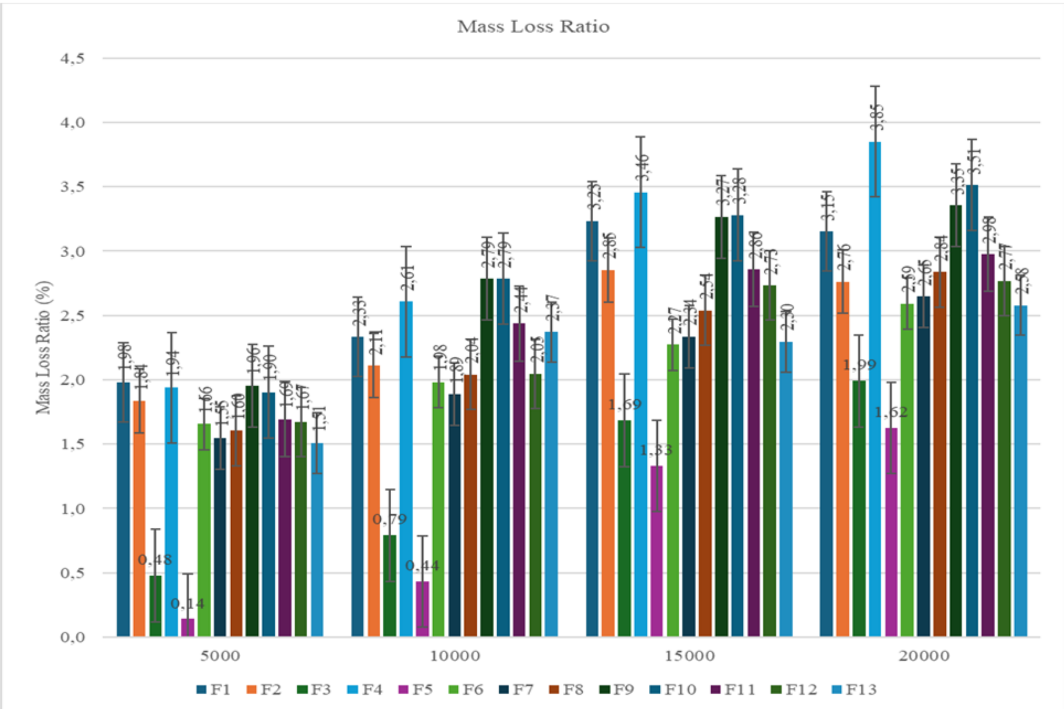

Figure 5. Mass loss ratio values of fabrics after 5000, 10000, 15000 and 20000 abrasion cycles

If the mass loss ratio values are examined in terms of treatment time, in wet ozone treated fabrics, at high concentrations, mass loss ratio values decreased as time increased. It can be said that as the treatment time increased, ozone had a greater effect on the fabric and contributed to the reduction in mass loss ratio values. At low concentrations, this change was not uniform. Concerning this result; the effect of treatment time can vary depending on treatment concentration. While examining the effect of treatment time in NaOCl treated and dry ozone treated fabrics, mass loss ratio values increased as treatment time increased at high concentrations. This was reversed at high concentrations in wet ozone treated fabrics and at low concentrations in dry ozone treated fabrics. Furthermore, the effect of treatment time can vary depending on the treatment type and concentration.

As a general result for the effects of the treatment parameters, the effects of treatment time, treatment type and treatment concentraion on the mass loss ratio values have changed depending on each other. Statistical analysis show that treatment time, treatment type and number of cycle have a statistically significant effect on mass loss ratio values (Table 9 and Table 10).

3.3 Tensile Strength and Tensile Elongation Results

Fabric tensile strength and elongation values in the warp and weft direction of all fabrics are given in Table 7 and graphically in Figure 6 and Figure 7.

Table 7. Tensile strength and elongation values of the fabrics with their %CV values

	Force at Peak				Strain at Peak			
Fabric Code	**Weft Direction**	**%CV**	**Warp Direction**	**%CV**	**Weft Direction**	**%CV**	**Warp Direction**	**%CV**
F1	646,740	2,631	1566,780	3,149	20,280	2,764	33,395	2,264
F2	648,740	4,170	1511,740	3,611	20,378	1,670	33,093	2,743
F3	622,700	4,102	1505,740	1,706	19,383	3,729	32,074	3,705
F4	634,500	9,878	1477,820	30,673	18,754	2,792	30,673	3,328
F5	625,620	6,966	1524,280	6,020	28,001	9,354	36,923	4,240
F6	620,180	4,667	1428,060	5,986	21,340	3,892	32,533	2,553
F7	624,480	4,612	1533,140	3,188	21,538	3,614	35,314	0,809
F8	607,320	1,604	1333,540	0,688	21,020	3,342	32,371	2,190
F9	629,140	7,074	1591,180	2,900	20,871	3,595	34,886	1,083
F10	644,240	7,678	1542,900	2,665	20,792	4,232	34,545	1,799
F11	654,720	4,000	1491,880	1,842	21,768	1,887	34,345	1,638
F12	594,140	5,776	1520,440	1,525	19,318	2,460	32,389	0,714
F13	723,820	2,813	1481,180	2,224	13,803	2,251	29,014	2,887

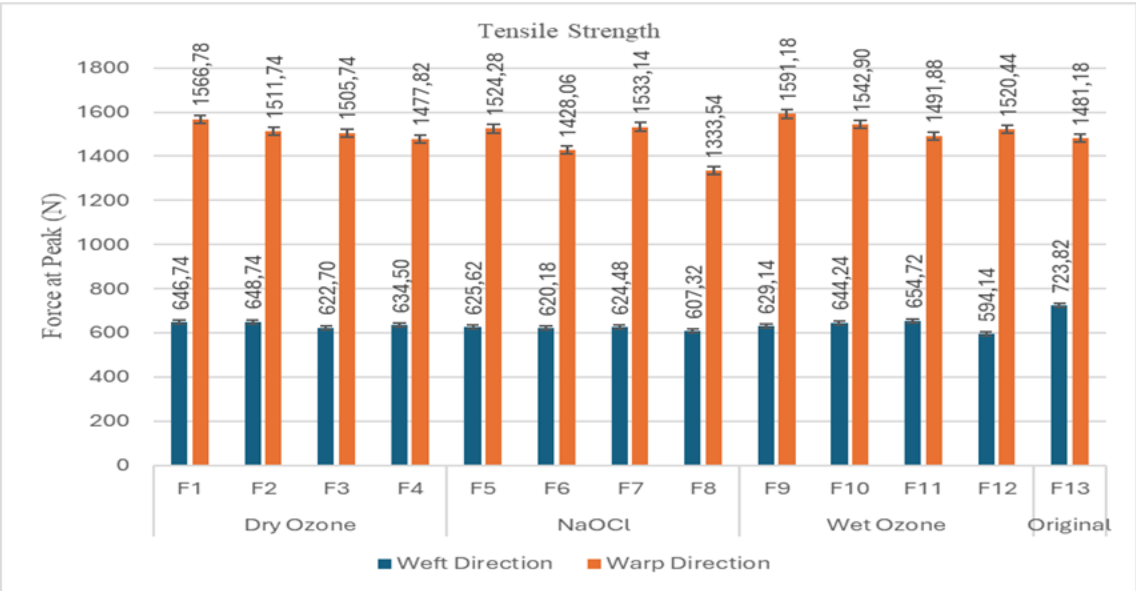

Figure 6. Tensile strength values of the fabrics.

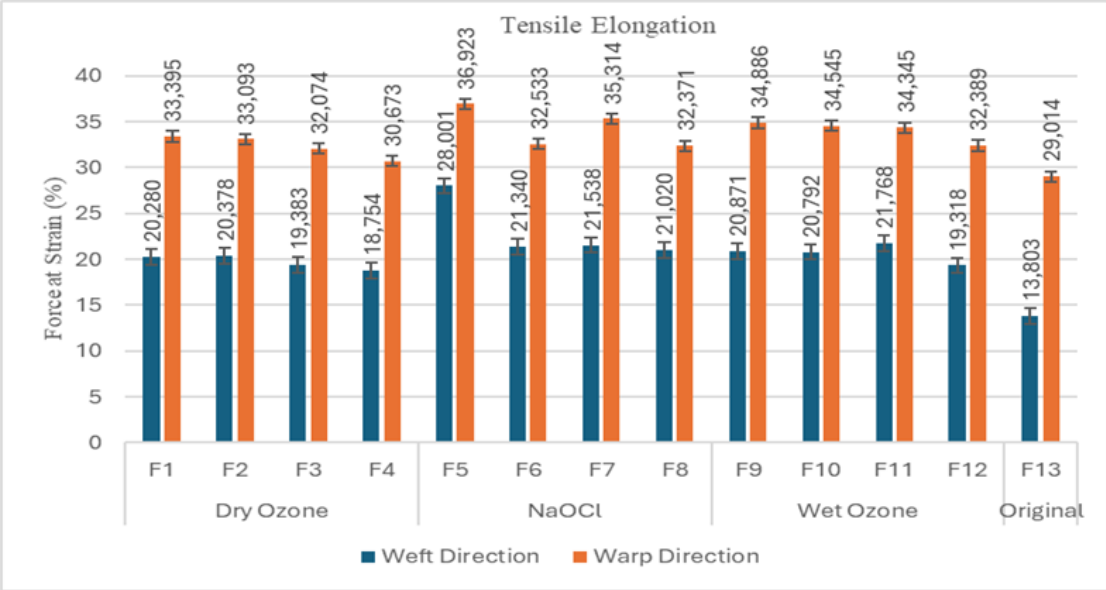

Figure 7. Tensile elongation values of the fabrics.

It is clear from Figure 6 that the tensile strength values in warp direction are higher those of in weft direction, as expected. In weft direction, the highest tensile strength value was observed in the original fabric, but in warp direction the higher tensile strength values were observed in treated fabrics than the original fabric in general. This result can be explained as the fabrics having higher weight per square meter as a result of the processes they were undergone and therefore the tensile strength values might be increased. These results in warp direction can be supported with the literaure [22].

In terms of treatment concentration, in general, the increase in treatment concentration had a decreasing effect on tensile strength values in the warp and weft direction in alignment with literature [17, 23]. Besides, in the warp direction, it was observed that the tensile strength values decreased as the treatment time increased, as expected [17, 19]. On the other hand, in the weft direction, no regular change was observed with respect to treatment time.

In the warp direction, the highest tensile strength values were generally observed in ozone treated fabrics, while the lowest tensile strength values were observed in NaOCl treated fabrics. In ozone treated fabrics, wet ozone treated fabrics also exhibited higher tensile strength than dry ozone treated fabrics in general. This result can be interpreted as the wet process increasing weight per square meter of the fabric, resulting in higher tensile strength. A comparison of the tensile strength values on the basis of the treatment type reveals out that, in the weft direction, the lower tensile strength values were generally observed in NaOCl treated fabrics, while the higher tensile strength values were observed in dry ozone treated fabrics. Therefore, in both directions, ozone treated fabrics exhibited higher tensile strength compared to NaOCl treated fabrics. The superiority of dry and wet ozone treated fabrics in terms of tensile strength varied depending on the fabric direction.

Statistical analysis show that there is a statistically significant difference for tensile strength according to fabric direction (Table 9 and Table 10).

When the tensile elongation values according to the fabric direction are examined as seen Figure 7, tensile elongation values in warp direction are higher those of in weft direction, as expected.

Upon evaluating the treatment type, it was observed that the treated fabrics had higher tensile elongation values than those of original fabric. This result can be interpreted as the tensile elongation increased after the processes. In evaluation made according to treated fabrics, in general tensile elongation values were lower in ozone treatment fabrics than in NaOCl treated fabrics. Considering how the tensile elongation values change depending on treatment time and concentration, increasing the treatment time and treatment concentration had a lowering effect on tensile elongation values in the warp direction. This result was also mostly observed in the weft direction.

While looking at the statistical analysis, fabric direction and treatment type have statistically significant effect on tensile elongation values (Table 9 and Table 10).

3.4. Bending Rigidity Test Results

Bending rigidity values in the warp and weft direction of all fabrics are given in Table 8 and graphically in Figure 8.

It can be seen from Figure 8, bending rigidity values in warp direction are higher than those of weft direction. On the other hand, bending rigidity values decreased as the treatment time increased for the fabrics treated NaOCl in both directions and treated ozone in warp direction. It can be stated that increasing treatment time had a reducing effect of the stiffness of these fabrics. For NaOCl treated fabrics in both directions and dry ozone treated fabrics in warp directions, bending rigidity values increased with increasing concentration. On the other hand, the values were increased only slightly for wet ozone treated fabrics in warp direction as the concentration increased. The increasing effect of concentration on fabric stiffness observed for all treatment types.

It was also found that bending rigidity values of original fabric are higher than treated fabrics in warp direction. It was observed that ozone treatment had a reducing effect on bending rigidity values and this result is compatible with literature [40]. While examining the bending rigidity values, the highest values of mean bending rigidity were observed in fabrics with NAOCl treatment for similar treatment time and concentration and this result is supported by the literature [20]. For similar treatment time and concentration, the values of wet ozone treated fabrics were generally higher than those of dry ozone. According to statistycal evaluation tables (Table 9 and Table 10), bending rigidity values were statistically significantly affected by fabric direction.

Table 8. Bending rigidity values of fabrics

Fabric Code	Weft Direction	%CV	Warp Direction	%CV	Mean
F1	61,2	1,851	180,4	3,684	105,1
F2	62,4	2,511	147	4,77	95,8
F3	56,6	4,821	180,9	4,806	101,2
F4	60,7	4,969	174,7	1,914	103
F5	67,4	3,268	186,9	1,68	112,2
F6	58,1	7,226	174,7	2,044	100,7
F7	74	11,785	201,3	7,61	122,1
F8	61,8	5,045	189	1,363	108,1
F9	61,9	4,256	190,9	1,665	108,7
F10	52,8	6,048	183,1	4,282	98,3
F11	49,2	6,851	190	1,738	96,6
F12	63,2	2,5	179,6	4,46	106,5
F13	33,2	5,422	253,1	2,038	91,7

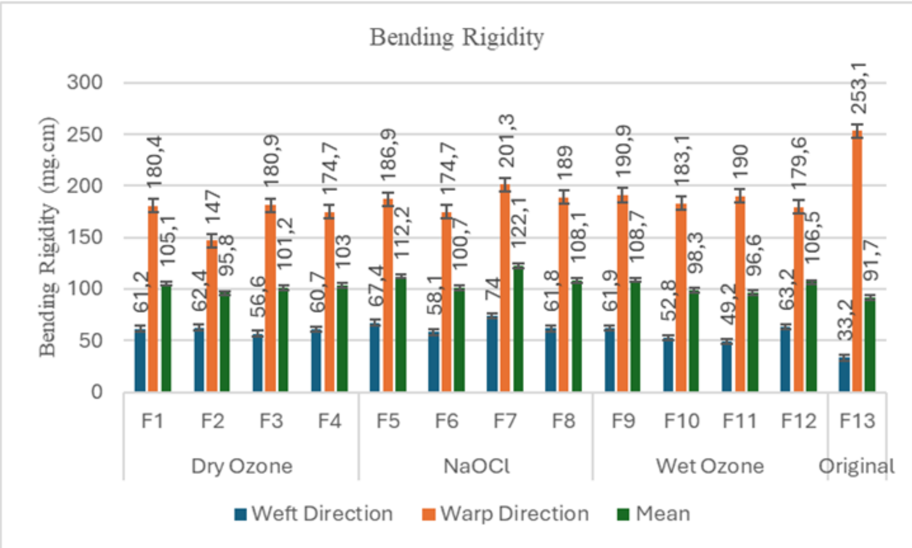

Figure 8. Bending rigidity values of the fabrics

Table 9. 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)**
Air permeability	Treatment Concentration	0,504	0,479	0,472
	Treatment Time	9,034	0,003	0,549
Mass Loss Ratio	Treatment Concentration	0,152	0,697	0,538
	Treatment Time	10,664	0,001	0,004*
Tensile Strength	Treatment Concentration	2,812	0,096	0,698
	Treatment Time	6,968	0,009	0,643
	Fabric direction	11,627	0,001	0,000*
Tensile Elongation	Treatment Concentration	0,000	0,998	0,212
	Process time	0,430	0,513	0,136
	Fabric direction	0,306	0,581	0,000*
Bending Rigidity	Treatment Concentration	1,856	0,176	0,672
	Process time	3,693	0,057	0,486
	Fabric direction	15,910	0,000	0,000*

Table 10. The one-way analysis of variance table for the results.

		One-Way ANOVA	
		F	**Sig.**
Air permeability	Treatment Type	1163,344	0,000*
Mass Loss Ratio	Treatment Type	7,597	0,000*
	Number of Cycle	28,930	0,000*
Tensile Strength	Treatment Type	0,107	0,956
Tensile Elongation	Treatment Type	3,448	0,019*
Bending Rigidity	Treatment Type	0,493	0,688

*: Statistically significant for α =0.05

3.5 Rubbing and Washing Fastness Test Results

According to Table 11, dry rubbing fastness values of the fabrics were found to be similar among all. When the wet rubbing fastness values were examined, the best wet rubbing fastness was observed in wet ozone treated fabrics, while the lowest wet rubbing fastness values were observed in dry ozone. It can be stated that dry ozone treatment negatively affected wet rubbing fastness. While examining the original fabric, it showed similar wet rubbing fastness with dry ozone treated fabrics. Additionally, increasing treatment time in dry ozone and NaOCl improved the wet rubbing fastness values. No regular change was observed according to concentration.

It can be seen from Table 12, apart from color change, washing fastness values of staining to wool, acrylic, polyester, nylon, cotton and acetate were found to be similar among all fabrics. It means that ozone treatment has no disadvantage in terms of staining according to NaOCl treatment. Regarding color change, only wet ozone treated fabric had 4-5 values in all parameters. Therefore, wet ozone treatment can be interpreted as advantageous compared to dry ozone treatment and NaOCl treatment in terms of color change after washing.

Table 11. Dry and wet rubbing fastness values of fabrics

Fabric Code	Dry		Wet	
	Width	Length	Width	Length
F1	4-5	4-5	2-3	2-3
F2	4-5	4-5	3	2-3
F3	4-5	4-5	2-3	2-3
F4	4-5	4-5	3	3
F5	4-5	4-5	3-4	3-4
F6	4-5	4-5	4	4
F7	4-5	4-5	3	3
F8	4-5	4-5	4	4
F9	4-5	4-5	4-5	4-5
F10	4-5	4-5	4-5	4-5
F11	4-5	4-5	4-5	4-5
F12	4-5	4-5	4-5	4-5
F13	4-5	4-5	2-3	2-3

Table 12. Washing fastness values of fabrics

Fabric Code	Staining						Color Change
	Wool	Acrylic	Polyester	Nylon	Cotton	Acetate	
F1	4-5	4-5	4-5	4-5	4-5	4-5	4
F2	4-5	4-5	4-5	4-5	4-5	4-5	4
F3	4-5	4-5	4-5	4-5	4-5	4-5	4-5
F4	4-5	4-5	4-5	4-5	4-5	4-5	4-5
F5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
F6	4-5	4-5	4-5	4-5	4-5	4-5	4
F7	4-5	4-5	4-5	4-5	4-5	4-5	4-5
F8	4-5	4-5	4-5	4-5	4-5	4-5	4-5
F9	4-5	4-5	4-5	4-5	4-5	4-5	4-5
F10	4-5	4-5	4-5	4-5	4-5	4-5	4-5
F11	4-5	4-5	4-5	4-5	4-5	4-5	4-5
F12	4-5	4-5	4-5	4-5	4-5	4-5	4-5
F13	4-5	4-5	4-5	4-5	4-5	4-5	4

4. CONCLUSION

In this study, 13 different denim fabrics were used: original, dry ozone treated, wet ozone treated and NaOCl treated fabrics. These fabrics were compared in terms of air permeability, abrasion resistance, tensile strength, tensile elongation, bending rigidity and rubbing and washing fastness properties. The effects of treatment type, treatment time and concentration and fabric direction on these properties were investigated. The results were evaluated comparatively and analyzed statistically.

About the results in terms of treatment type; it was observed that ozone treated fabrics had higher air permeability values than NaOCl treated fabrics. Besides, the highest tensile strength values were generally observed in ozone treated fabrics while their tensile elongation values were lower. It was observed that the mass loss ratio values were lower in NaOCl treated fabrics those of ozone treated fabrics for low concentration. Ozone treated fabrics had advantages in terms of bending property. Besides, the wet ozone treated fabrics were superior to other fabrics in terms of rubbing fastness and color change after washing.

Considering the effect of treatment concentration; the effect on air permeability property varied depending on treatment time. For tensile strength values, in general, the increase in treatment concentration had a decreasing effect on tensile strength values. In terms of treatment time, in the warp direction, it was observed that the tensile strength values decreased as the treatment time increased. Besides it was also observed increasing the treatment time and treatment concentration mostly had a lowering effect on tensile elongation values. On the other hand, air permeability values increased as the treatment time increased for the dry ozone treated fabrics. For mass loss ratio values, the effects of treatment time, treatment type and treatment concentraion on the values have changed depending on each other in general. On the other hand, examining fastness values, increasing treatment time in dry ozone and NaOCl improved the wet rubbing fastness values.

The study revealed out that while sustainable ozone treatment can exhibit superior properties in optimal treatment conditions in terms of the properties examined, it also does not pose a major disadvantage compared to NaOCl. To compare dry and wet ozone treatment within, majority of the fabrics with superior test results were belonged to the group of dry ozone treated ones. When the test results were evaluated from the aspect of air permeability, abrasion resistance, tensile strength, bending rigidity and rubbing and washing fastness values, fabric F3 and fabric F12 were found to be the optimum fabrics giving the results of above average for dry and wet ozone treatment, respectively. On the other hand, regarding fading effects, fabric F12 presented superior appearance supporting the applicability of the wet ozone treatment. From this perspective, ozone treatment is both sustainable and offers advantages in terms of fabric properties. For future studies, it is thought that changing the processing conditions in an appriopriate scale will lead to enhance the frame to investigate variable characteristics of the denim fabrics and will support the usability of ozone treatment as a sustainable method.

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