NO STONE TECHNOLOGY: REVOLUTIONIZING DENIM WASH FOR SUSTAINABLE FASHION

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Abstract: *The denim sector has to deal with secondhand trash, unsalable inventory, and processed waste. Although the process of recycling garbage is sustainable, it is not. Enthusiasts can use zero water technologies, ozone washes, stone-free technology, less hazardous dyeing and washing techniques, and advanced organic denim to enhance the denim experience. By transforming the way denim is treated, this technology may enhance worker safety and the environment NoStone® technology eliminates pumice stone in washing machines, offering a reusable, robust solution with easy-lock features, eliminating pollutants from extraction, transportation, and processing, and being lightweight and sustainable. This paper's primary goals are to examine water consumption and carbon footprint utilizing the no-stone approach and the ETP value for sustainability evaluation. This research also shows the sample's appearance before and following a stone-free wash. The denim's characteristics and aftercare cycle evaluation are also examined using a range of tests.*

Key words: Denim, Sustainability, Pumice stone, NoStone.

TEHNOLOGIJA BEZ KAMENJA: REVOLUCIJSKO PRANJE DENIMA ZA ODRŽIVU MODU

Apstrakt: *Sektor teksasa mora da se bavi sekundarnim otpadom, inventarom koji se ne može prodati i prerađenim otpadom. Iako je proces reciklaže otpada održiv, nije. Entuzijasti mogu da koriste tehnologije bez vode, pranje ozonom, tehnologiju bez kamenja, manje opasne tehnike bojenja i pranja, kao i napredni organski teksas da poboljšaju iskustvo teksasa. Transformisanjem načina na koji se teksas tretira, ova tehnologija može poboljšati bezbednost radnika i životnu sredinu. Nostone® tehnologija eliminiše plavac u mašinama za pranje veša, nudeći robusno rešenje za višekratnu upotrebu sa funkcijama lakog zaključavanja, eliminišući zagađivače iz ekstrakcije, transporta i obrade, i da je lagan i održiv. Primarni ciljevi ovog rada su ispitivanje potrošnje vode i ugljeničnog otiska koristeći pristup bez kamena i ETP vriednost za procenu održivosti. Ovo istraživanje takođe pokazuje izgled uzorka pre i nakon pranja bez kamenja. Karakteristike teksasa i procena ciklusa posle nege se takođe ispituju korišćenjem niza testova.*

Ključne reči: teksas, održivost, plovućac, bez kamena.

1. INTRODUCTION

Denim is a special type of cotton fabric manufactured from indigo dyed warp and undyed weft in warp faced twill pattern [1]. Initially intentioned for miners, Denim has been used extensively by people from all demography, ages, genders and classes which no other fabric has achieved. For this, denim is often considered as a timeless fashion [2, 3]. Denim wash is a popular method to attain enhanced outlook, durability and comfort [4, 5]. However, processing denim in conventional methods alerts serious threats. It is estimated that around 90% textile dyes alongside toxic wastewater are discharged on effluents of garments industries [6-8]. Various scientific studies have identified the mutagenic effects of textile samples and wastewater from the textile industry. Their findings showed that chemicals used for textile finishing are mainly responsible for the mutagenic effects, responsible for disrupting food chain in rivers and canals [10, 11]. The washing processes of denim emits 60% of total Greenhouse gases [12]. Which is why sustainability has been considered a noble process to reduce wastages of water, chemical and carbon footprint [13].

Stone wash gives denim a worn out and vintage outlook by damaging the fabric with pumice stone [4]. The pumice stone for Stone wash requires more water to remove, can clog washing machines, sewer lines and create an undesired impact on effluent [4, 14-19].

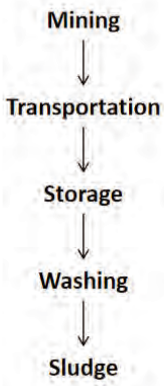

Figure 1: Life cycle of Pumice Stone

Figure 1 shows the life cycle of pumice stone for stone washing. The requirement for mining, transport, storage, machine maintenance and waste disposal of pumice stone cause large amount of carbon footprint [20, 21]. No Stone is a novel technology developed by Tonello. It consists three level of abrasive stainless-steel drum (Figure 2) which are easily movable. When rotating the abrasion between the steel drum and denim cause damage of denim, creating a worn-out look. No Stone is a reusable system that eliminates the need for pumice stone in washing machines including the entire life cycle shown in figure 1. It is easy to use, lightweight, and requires no extra handling of garments, unlike traditional methods. It is more responsible as it does not generate dust, sludge, or microparticles that can clog filters or pipes. It has a long service life and can be regenerated. No Stone is less cumbersome than traditional stone-washing systems, as it is slim, stackable, and not bulky when not in use. It also saves on costs associated with the disposal, purification, and maintenance of washing machines. Additionally, it achieves the same taste as traditional stonewash with less water, as it allows for skipped like surfactants or auxiliary compounds are used to improve enzyme activity or produce certain effects like color fading. Enzyme activity is maximized by meticulously regulating the pH of the washing solution. Uniform enzyme application is guaranteed by mechanical agitation in washing machines across the clothing. The procedure is regulated at particular temperatures and times to optimize enzyme efficacy while preventing fabric damage. Any remaining chemicals and enzymes are removed from the denim by giving it a good wash after treatment. It is possible to apply further treatments, such as softening agents or dyes, to improve the feel of the fabric or create particular visual effects [16, 21].

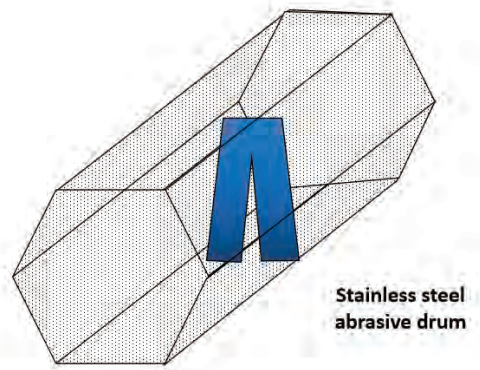

Figure 2: Mechanism of stone free wash with NoStone®

Globalization has led to fast fashion, where clothing is produced cheaply, causing people to consider it disposable. This has led to the depletion of natural resources and increased waste. The recycling industry must handle the discarded clothes and home textiles, creating a double-edged sword that stimulates the economy but also poses issues with apparel and textile disposal[22].Sustainable apparel wash is a rising trend aimed at reducing the environmental effect of the clothes washing process. Sustainable clothing washing techniques include utilizing less water and energy, using environmentally friendly detergents and

chemicals, and decreasing waste. There are several advantages to using an environmentally friendly garment wash. First and foremost, it contributes to reducing the fashion industry's environmental impact. Second, it may help businesses save money on their water and energy bills. Third, sustainable washing procedures can help minimize premature fading and damage, hence improving clothing quality. Conventional denim washing techniques may be damaging to the environment since they consume significant amounts of water and energy and generate toxic wastewater[23].The development of more environmentally friendly methods for washing jeans has drawn increased attention in recent years. Through the use of less water, energy, and chemicals, these procedures seek to lessen the negative effects of denim washing on the environment. Numerous eco-friendly denim washing methods are available, such as enzyme washing, laser washing, ozone washing, and e-Flow (nanobubble technology) washing. Denim producers may lessen the environmental impact of their goods and satisfy the rising demand for sustainable fashion by employing sustainable denim washing techniques [24].

EIM (Environmental Impact Measuring) software stands out because it is the sole software capable of quantifying the ecological consequences of garment finishing techniques. Additionally, it serves as a powerful self-validation instrument that allows manufacturers, brands, and retailers to monitor the amount of energy, water, and chemicals utilized in the creation of their products, as well as any potential health hazards for personnel. Our objective is to enhance EIM by converting it into a user-friendly platform that integrates another venture. A working group comprising various EIM users integrates further industry initiatives into the tool management, enabling brands and garment finishers to upgrade EIM software according to their interests. The environmentally friendly features of EIM solve problems by reducing the need for energy, water, and less polluted chemicals for easier decision-making [25]. The resolution of a moral dilemma is an additional factor. Removing potentially harmful chemicals and physical labor has a detrimental effect on the health of employees. Avoiding rising product manufacturing costs enables rapid adoption, it is preferable to introduce new technology, procedures, or services only when it can produce the ideal product at a cost-neutral rate.

This research's primary goal is to apply the no-stone methodology to an examination of water use and carbon footprint using the ETP value for sustainability evaluation. Additionally, this study presents the sample's appearance both before and after a stone-free wash. Through a variety of tests, the denim's product characteristics and aftercare cycle assessment are also analysed.

2. MATERIALS AND METHOD

2.1 Materials

For this study denim sample was collected from a reputed washing plant in Bangladesh. The Wet process steps of stone wash and stone free wash. In stone free wash, the process of stone wash is carried out in the abrasive stainless-steel drum of No Stone® machine with neutral cellulase enzyme in granular form for 14 min at 45°C thus eliminating the step of stone wash and excess rinsing following (Table 1).

Table 1: Materials and methods with specification

SL.	Materials and Methods	Specification
1	Fabric construction	3/1 warp-faced twill, 500 GSM
2	Fibre composition	99% Cotton, 1% Elastane
3	Primary machine	No Stone®
4	Primary operation	Substitution of stone wash

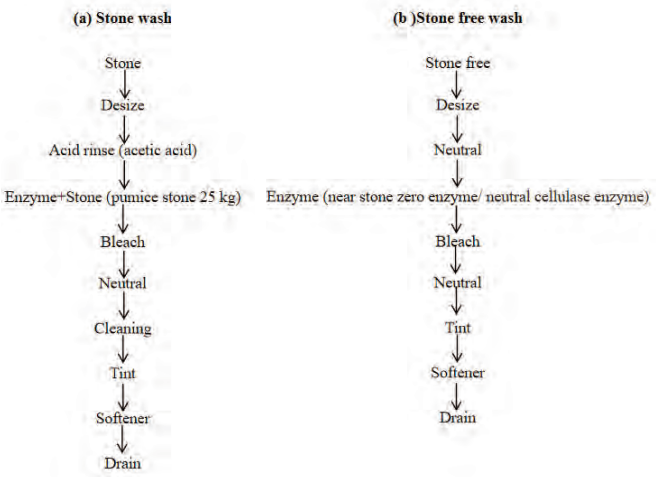

Figure 3: Wet process steps of stone wash and stone free wash

Figure 3 shows the wet process steps for both stone wash and stone free wash. In stone wash, 25 kg pumice stone was required for a single batch. Tinting of denim garment is usually done after the stone washing process. In this process, garment has been lightly coloured in order to give the final denim appearance

a slight shift. During tinting, a small amount of tint or color is added to the garment in order to change the hue/cast/tone of the indigo shade. However, when the quantity of tint color increases, it covers up indigo. This is not true over dyeing but merely gives the impression of a change in the overall color of the fabric.

2.2 Methods

To evaluate the sustainability of e-flow processes, a comparative study was carried out using the EIM software. The impacts on workers, chemicals, water, and energy are divided into separate categories by the EIM score (Table 2). The program pre-sets an environmental criterion against which the outcomes of each category are assessed. The overall influence of the process is sorted from low to high once each category has been classified separately. We understandably present the results using color coding. The range of EIM values is low impact (0–33), medium impact (33-66), and high impact (+66).

Table 2: EIM (Environmental Impact Measuring) software result display

EIM V2.0					
Category				EIM Score Range	
Water	Energy	Chemical Impact	Worker Impact		
0-45	0-2.5	0-33	0-13	Low impact	0-33
45-90	2.5-3.6	33-66	13-29	Medium impact	33-66
+90	+3.6	+66	+29	High impact	+66

Table 3 lists the various fabric tests, along with the industry standard technique used to quantify those attributes for this study. These tests were all performed at a reputable laboratory. Using the ISO 105-X12:2016, ISO 105-C06:2010, and ISO 105-E01:2013 standards, color fastness against rubbing, washing, and water was tested. The IS0 13937-1:2000 and ISO 13935-2:2014 standards were used to test tear force and seam force, while the IS0 13936-2:2004 standard was used to perform seam slippage. Tests make sure that products meet the required standards for quality. It helps manufacturers identify any flaws or concerns during the production process, allowing them to be fixed before a product being released onto the market. All of the research tests were conducted with the instruments listed in the table below.

Table 3: Test methods

Test name	Standard and Instruments
Color fastness to rubbing	ISO 105-X12:2016 Rubbing finger size: 16 mm dia.; Track length: 104.0 mm; Weight: 9.0N
Color fastness to washing	ISO 105-C06:2010 Gyrowash
Colour fastness to water	ISO 105-E01:2013 Perspiration tester
Tear force	IS0 13937-1:2000 Elma tear testing machine (pendulum method)
Seam force	ISO 13935-2: 2014 Constant rate of elongation (CRE) machine (grab method)
Seam slippage	IS0 13936-2:2004 Constant Rate of Extension machine

3. RESULTS AND DISCUSSIONS

3.1 Sustainability of stone free wash in No Stone compared with Stone wash

The study showed effects of stone free wash in No Stone compared with stone wash. Table 4 summarizes the comparison between stone wash and stone free wash in terms of water consumption and carbon footprint. The data in table shows that for every piece of denim garment, stone free wash requires 50.68 litre less water compared to stone wash with an efficiency of 60.13%. In addition, stone free technology uses 15% renewable water for every piece of denim. As pumice stone requires an excess rinsing to be completely removed, replacing pumice stone with No Stone conserves more water. Eliminating stone wash also results less manual work related with pumice stone mining, transportation and maintenance. As shown in data stone free wash emits 0.34 kg of CO_2 per piece of garment, resulting less carbon footprint with 80.95% efficiency. The elimination of using pumice stone in washing also conserves energy by using novel technology. The No Stone technology uses 1.04 kilo Watt hour energy per garments with application of 30% renewable energy compared to conventional stone washing which required 1.29 kilo Watt hour energy per garments, resulting 19.37% efficiency. When compared to conventional stone washing techniques, stone-free solutions such as enzyme treatments use less water, energy, and waste, thereby lowering car-

bon footprints. These techniques minimize resource consumption and waste through effective procedures such targeted bio-friendly enzymes, which lessens the total influence on the environment [26].

Table 4: Comparison between stone wash and stone free wash in terms of water consumption and carbon footprint

	Stone wash	Stone Free wash	Use of renewable water and energy in stone free wash
Water (litre/ garment)	84.28	33.60	5.04
Energy Impact (kWh/ garment)	1.29	1.04	0.311
Carbon Footprint (kg CO_2/garment)	0.42	0.08	-

Table 5 shows the comparison of effluent treatment plan (ETP) values for stone wash and stone free wash in NoStone. In conventional stone wash, the COD and BOD levels are at 120 mg/L and 97 mg/L respectively which are reduced to 78 mg/L and 45 mg/L in stone free wash with NoStone. Lower COD, BOD results less mitigation in canal river. As the process of stone wash with pumice stone replaced by NoStone in stone free wash, no sludge from stones and waste water is produced which reduces 452 mg/L of TDS value and 114 mg/L of TSS value. Lower TDS, lower solid dissolved resulting less hardness. Abrasive activity with pumice stone results high TSS value which is reduced in stone free wash [27].

Table 5: Comparison of ETP Value between stone wash and stone free wash

ETP value	Stone wash	Stone free wash
Chemical Oxygen Demand (mg/L)	120	78
Biological Oxygen Demand (mg/L)	97	45
Total Dissolved Solid (mg/L)	1964	1512
Total Suspended Solid (mg/L)	368	254

Figure 4 shows the efficiency of Stone free wash over conventional stone wash for different parameters of ETP. The parameters in question holds significant value when evaluating the quality of water due to its impact on aquatic species. At 53.60%, No Stone washing has the highest efficiency in terms of BOD, with 35% for COD, 30.97% for TSS and 23.01% for TDS. Such efficiency of stone free wash contributes significantly to the physical and visual deterioration of the sediment, and is a useful indication of other contaminants, especially nutrients and metals transported on the surfaces of suspended sediment.

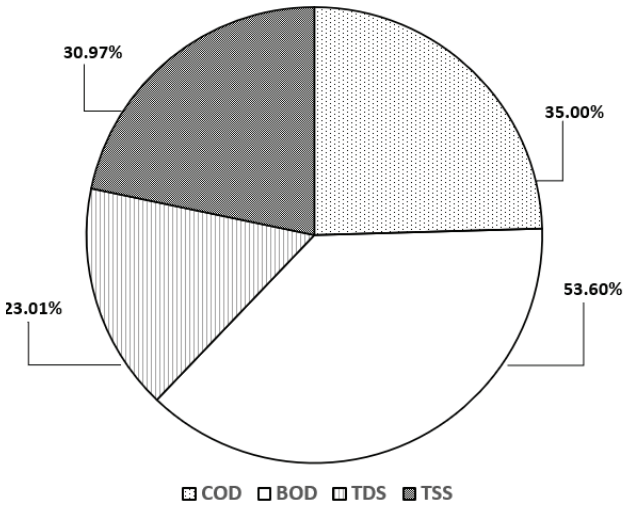

Figure 4: Efficiency of No Stone wash for ETP.

Table 6 summarizes the comparison of stone wash and stone free wash in in EIM software in terms of EIM score of water, energy, chemical and worker impact. This study uses the EIM score to measure sustainability throughout the production process. It is observed that No Stone technology has a negligible environmental impact in terms of water, energy, chemicals, and worker effects. Water consumption has an EIM score of 23.2, indicating a low influence on water usage. The energy consumption value also indicates a minimal effect on energy utilization. Chemicals and workers' impact values are low because of the reduced need for labor in stone free wash, resulting in lower impact ranges.

3.2 Product Quality

The development of No Stone Technology, which completely changes the paradigm from conventional procedures to more ecologically friendly practices, represents a significant leap in denim washing processes within the context of sustainable fashion. This technological innovation allows for a critical examination of product quality, which is defined as the extent to which

Table 6: EIM score

Category	EIM Score	Standard	Parameter (EIM Score)				
			EIM Score Range	Water	Energy	Chemical Impact	Worker Impact
Total score	33	Low impact	0-33	0-45	0-2.5	0-33	0-13
Water consumption	23.2						
Energy use	2.3	Medium impact	33-66	45-90	2.5-3.6	34-66	14-29
Chemical consumption	15.5	High impact	+66	+90	+3.6	+66	+29
Workers' impact	15						

a product satisfies client requests, meets expectations, and performs its intended purpose. Using pumice stones to give denim a faded, worn-in appearance is known as traditional stone washing, as seen in Figure 5 (a). Although this technique is good at producing the desired look, it has a number of disadvantages, such as the possibility of destroying the integrity of the fabric, inconsistent results from the wash, and significant environmental effects from the high water and energy consumption as well as the waste stone production.

On the other hand, Figure 5 (b) shows denim treated with No Stone Technology, which uses alternative techniques such enzyme treatments to do away with the requirement for abrasive stones. Samples 5(a) and 5(b) differ slightly in look, however No Stone Technology not only accomplishes a similar aesthetic but also overcomes the drawbacks of conventional techniques. Because physical abrasives are not used in the No Stone method, fabric durability is preserved, wash results are more consistently achieved, and the environmental effect is greatly reduced by using less water, energy, and trash. Therefore, the small difference in appearance between the two samples highlights how No Stone Technology has been successfully applied to uphold product quality while promoting environmentally friendly denim production methods

Table 6 shows the assessment of sample appearance after care cycle. The assessment of denim samples after the No Stone Technology wash cycle highlights several significant findings that underscore the technology's efficacy in promoting sustainable fashion without compromising material integrity. The evaluation, based on various standardized tests, demonstrates that the No Stone Technology achieves desirable results in multiple facets of denim care. Firstly, the color change was assessed using Grey Scale ISO 105-A02, where the samples achieved a score of 4, meeting the required range of 3-4 or better, thus indicating minimal alteration in hue and consistency in appearance after the care cycle. The appearance of the sample after stone free wash has been assessed by ISO 6330:2021 [28]. The following parameters are

(a) (b)

Figure 5: Denim sample: (a) after stone wash, (b) after stone free wash

major concern in stone free wash, due to prolonged abrasion there are risk of detachment of trims, material breakage, malfunction of zipper and corrosion. After a particular amount of care cycle, a sample from stone free wash was assessed. It was observed that the sample fulfilled the requirements of assessment and was found to be accepted by the test. Grey scale rating is based on the step of 1 to 5, where 1 is bad and 5 is good. The assessment of denim samples after the No Stone Technology wash cycle highlights several significant findings that underscore the technology's efficacy in promoting sustainable fashion without compromising material integrity. The evaluation, based on various standardized tests, demonstrates that the No Stone Technology achieves desirable results in multiple facets of denim care. Firstly, the color change was assessed using Grey Scale ISO 105-A02, where the samples achieved a score of 4, meeting the required range of 3-4 or better, thus indicating minimal alteration in hue and consistency in appearance after the care cycle. This suggests that the technology maintains the original dye integrity of the denim, which is crucial for preserving the aesthetic appeal of the garment while minimizing the impact on the dyeing process typically associated with traditional denim washing. In terms of cross staining, the samples scored a 4 according to Grey Scale ISO 105-A03, which falls within the acceptable range of 4-5 or better. This result confirms that the No Stone Technology effectively prevents unwanted transfer of color between denim components, thereby upholding the visual quality and preventing the potential degradation of garment components through color bleed. The pilling assessment yielded a score of 5, surpassing the minimum requirement of 3-4, highlighting the technology's ability to maintain fabric smoothness and resistance to pilling. This is particularly important for sustainable fashion, as it extends the lifespan of denim garments and reduces the frequency of replacement, contributing to overall resource conservation. Furthermore, the evaluation of fastenings and trims, material breaks, function of zippers/closures, and corrosion/damage to trims all resulted in "No Change", underscoring the technology's gentle yet effective treatment of denim. This absence of damage indicates that the No Stone Technology does not compromise the structural integrity or functionality of the garment, thus reinforcing its suitability for use in sustainable fashion practices. By preventing material damage and maintaining garment quality, the technology not only supports environmental sustainability through reduced use of harmful chemicals and resources but also promotes durability and longevity in denim products. Overall, these assessment results affirm that the No Stone Technology represents a significant advancement in denim washing processes, aligning with the growing demand for eco-friendly and high-performance fashion solutions.

Table 6. Assessment of sample appearance aftercare cycle

Assessment	Observation	Requirement	Comment
Colour change Grey Scale ISO 105-A02	4	3-4 or better	Passed
Cross staining on component(s) Grey Scale ISO 105-A03	4	4-5 or better	Passed
Pilling	5	Min 3-4	Passed
Detachment of fastenings and trims	No Change	No Change	Passed
Materials breaks	No Change	No Change	Passed
Function of zipper/closure	No Change	No Change	Passed
Corrosion/Damage to trim	No Change	No Change	Passed

Table 7 presents the denim's product characteristics following a stone-free No stone wash using several testings. A notable improvement in fabric performance and sustainability is indicated by the test results for No Stone Technology in denim washing. The fabric received a strong score of 4, above and beyond the required minimum of 3–4, in the color fastness tests, which assess its resistance to fading from

Table 7: product parameters of denim after stone free wash through various tests

Tests	Requirement	Finding
Colour fastness to rubbing	3-4	4
Colour fastness to washing	3-4	4
Colour fastness to water	3-4	4
Tear force (N)	Min. 30 (warp way)	46.3
	Min. 24 (weft way)	26.6
Seam force (N)	Min. 260	265.6 (in seam)
		294.2 (side seam)
		458.6 (seat)
		354.4 (back rise)
		275.6 (front rise)
Seam slippage (mm)	Max 6	0 (in seam)
		2 (side seam)

rubbing, washing, and exposure to water. Because it implies that the denim will hold up over time and not need to be replaced as frequently, this high level of color fastness is essential for sustainable fashion and reduces the impact on the environment.

The denim has noteworthy strength when measured by tear force, a measure of a material's resistance to tearing. The fabric has a rip force in the warp direction of 46.3 N, which is significantly higher than the minimum of 30 N. This means that the fabric will last longer under stress and won't tear easily. Nevertheless, the weft direction rip force of 26.6 N is somewhat less than the minimum required, indicating a possible area for development since it might impact the overall longevity of the fabric. Each seam force result is far greater than the minimum needed strength of 260 N, indicating that the seams are strong. The force applied to the in-seam is 265.6 N, whereas the side seam, seat seam, rear rise seam, front rise seam, and seat seam are all 294.2 N, 458.6 N, and 354.4 N, respectively. In order to guarantee that clothing retains its structural integrity and durability over time, it is essential that the seams be strong and able to bear significant stress, as these data show. Another significant component is seam slippage, which quantifies the amount of fabric stretch at the seam. The tested findings indicate 0 mm for the in-seam and 2 mm for the side seam, whereas the maximum permissible seam slippage is 6 mm. These low numbers imply that the fabric has superior seam stability, which lowers the risk of a seam failing and improves the functionality of the garment. The findings show that denim treated with No Stone Technology performs exceptionally well in terms of color fastness, robustness, and seam strength while also showing very little seam slippage[29]. Together, these features strengthen the technology's ability to promote sustainable design by creating high-quality, long-lasting clothing with a smaller environmental effect.

4. CONCLUSION

The study found that No Stone is a sustainable and eco-friendly method for denim washing technology due to its high energy and water efficiency. The testing parameters showed that No Stone is sustainable in terms of water, carbon footprint and energy consumption, with 60.13%, 80.95% and 19.37% efficiency in addition to renewable usage of water and energy (15% and 30%, respectively). This technology has no environmental impact on water and energy use, making it a cost-effective and efficient option for denim washing. Moreover, due to elimination of pumice stone for

washing, No Stone provides a big improvement ETP and sludge management by reducing the parameters of ETP during denim wash. The overall EIM score is 33 which proves the sustainability of this technology. After stone free wash, it was observed that the denim sample met the requirements of appearance assessments and test standards. Therefore, it can be concluded that No Stone meets requirement for product quality while maintaining the sustainability and balance of the environment. The study did not provide a comprehensive analysis of collaborating of other sustainable practices like ozone and nebulization. More research is required for the mentioned field.

REFERENCES

[1] Annapoorani, S. (2017). Introduction to denim, *Sustainability in denim*, Woodhead Publishing, Elsevier, Cambridge, 1-26.

[2] Amutha, K. (2017). Environmental impacts of denim, *Sustainability in Denim*, Woodhead Publishing, Elsevier, Cambridge, 27-48.

[3] Periyasamy, A.P., Ramamoorthy, S.K., Lavate, S.S. (2018). Eco-friendly Denim Processing, *Handbook of Ecomaterials*, International Publishing, Springer, p. 1-21.

[4] Shaw, V.P., Mukhopadhyay, A. (2022). Impact of abrasion on strength, elasticity and elastic recovery properties of stretch-denim fabric, *International Journal of Clothing Science and Technology,* 34(2), 241-261.

[5] Chequer, F., Olivera, G.A.R., Ferraz, E., Cardoso, J., Zanoni, M., Olivera, D.P. (2013). Textile Dyes: Dyeing Process and Environmental Impact, *Eco-Friendly Textile Dyeing and Finishing*. 6, 151-176.

[6] Roy Choudhury, A. K. (2013). Green chemistry and the textile industry. *Textile Progress*, *45*(1), 3-143. https://doi.org/10.1080/00405167.2013.807601

[7] Karthik, T., Gopalakrishnan D. (2014). Environmental Analysis of Textile Value Chain: An Overview, *Roadmap to Sustainable Textiles and Clothing: Environmental and Social Aspects of Textiles and Clothing Supply Chain,* Springer, Singapore, 153-188.

[8] Chia, M.A., Musa, R.I. (2013). Effect of indigo dye effluent on the growth, biomass production and phenotypic plasticity of Scenedesmus quadricauda (Chlorococcales), *Anais da Academia Brasileira de Ciências,* 86(1), 419-428.

[9] Rannug, U., Bramstedt H., Nilsson, U. (1992). The presence of genotoxic and bioactive components in indigo dyed fabrics-a possible heatlh risk? *Mutation Research Letters*, 282(3), 219-225.

[10] Ajibola, VO. (2001). Recovery of indigo from a textile effluent in Nigeria, *Journal of scientific and industrial research*, 60, 735-737.

[11] Samanta, K.K., Basak, S., Chattopadhyay, S.K. (2017). Environmentally friendly denim processing using water-free technologies, *Sustainability in denim*, Woodhead Publishing, Elsevier, Cambridge, 319-348.

[12] Pal, H., Chatterjee, K.N., Sharma, D. (2017). Water footprint of denim industry, *Sustainability in denim*, Woodhead Publishing, Elsevier, Cambridge, 111-123.

[13] Cavaco-Paulo, A. (1998). Mechanism of cellulase action in textile processes, *Carbohydrate polymers*, 37(3), 273-277.

[14] Khan, M.K.R., Jintun, S. (2021). Sustainability issues of various denim washing methods, *Textile & Leather Review*, 4(2), 96-110.

[15] Cheung, H.F., Kan, C.W., Yuen, C.W.M., Yip, J., Law, M.C. (2013). Colour fading of textile fabric by plasma treatment. *Journal of Textiles*, *2013*(1), ID 214706. https://doi.org/10.1155/2013/214706

[16] Ghoranneviss, M., Moazzenchi, B., Shahidi, S., Anvari, A., Rashidi, A. (2006). Decolorization of Denim Fabrics with Cold Plasmas in the Presence of Magnetic Fields, *Plasma Processes and Polymers*, 3, 316-321.

[17] Ondogan, Z., Pamuk, O., Öndoğan, E., Ozguney, A. (2005). Improving the appearance of all textile products from clothing to home textile using laser technology, *Optics & Laser Technology*, 37, 631-637.

[18] Karthik, T., Murugan, R. (2017). Carbon footprint in denim manufacturing, *Sustainability in Denim*, Elsevier, 125-59.

[19] NOSTONE THE STONE AGE IS OVER (Available from: https://tonello.com/en/component/nostone/)

[20] Chavan, R.B. (2014). Environmental Sustainability through Textile Recycling, *Journal of Textile Science & Engineering*, 2(2).

[21] Parvez, A.A., Sarker, U., Kawser, M.N., Rahim, A., Shahid, M.I. (2021). Superiority of Sustainable Ozone Wash Over Conventional Denim Washing Technique, *International Journal of Current Engineering and Technology*, 11, 516-522.

[22] Garcia, B. (2015). Reduced water washing of denim garments*, Denim: Manufacture, Finishing and Applications,* Woodhead Publishing, 405-423.

[23] Improve your ecological footprint 2024 (Available from: https://www.jeanologia.com/eim/.)

[24] Nahid-Ull-Islam, M., Hasan, S.M.M., Chowdhury, M.K.H., Sakib, S.I., Ahamed, S., Sayeed, M.A., Akter, M. (2024). Sustainable Approaches of Ozone Wash and Laser Fading Over Conventional Denim Wash, *Tekstilec*, 67(2), 104-118, https://doi.org/10.14502/tekstilec.67.2024011

[25] Shahid, M.I, Al Parvez, A., Rahim, A., Kawser, M.D.N., Sarker, U.K. (2021), Superiority of Sustainable Ozone Wash Over Conventional Denim Washing Technique, *International Journal of Current Engineering and Technology*, 11(5), 516-621.

[26] ISO 6330:2021 Textiles-Domestic washing and drying procedures for textile testing, Switzerland.

[27] Hasan, S.M.M, Ull-Islam, MN, Chowdhury, M.K.H., Akter, M., Sakib, M.S.I. (2024). Core 2.0 Nebulization Technique - A Sustainable Denim Finishing Approach, *Textile & Leather Review*, Vol. 7, 582-96.

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