

## **Advancing Circular Fashion: An Innovative Reuse Framework for Knit Denim Garments via Cold Bleaching, Dry Processing and Bio-polishing**

<sup>1</sup>Amjad Hossain

<sup>2</sup>Md Mahbubur Rahman

<sup>3</sup>S. M. Mahbubul Alam Shakil

<sup>4</sup>Sharmin Akter Mitu

<sup>5</sup>Md. Maniruzzaman Chowdhury Rubel

<sup>1,2,3,4</sup>Textile Engineering College, Zorarganj, Chattogram

<sup>5</sup>Tangail Textile Engineering College, Kalihati, Tangail

**Abstract:** This study investigates the feasibility of fostering the sustainability of used knit denim through an integrated upcycling approach involving cold bleaching, dry processing, bio-polishing, and softening. This research is oriented toward reducing water consumption, chemical waste, and textile landfill contributions. The study also evaluates how well upcycled denim performs both physically and chemically in large-scale manufacturing settings. A sample of worn knit denim pants was cleaned with detergent and treated sequentially with eco-friendly processes: cold bleaching (using calcium hypochlorite), dry mechanical techniques (e.g., PP spray for localized fading), enzymatic bio-polishing to reduce fiber pilling, and softening agents to improve tactile quality. Data were analyzed through comparative assessments of tearing strength, color fastness (to wash, perspiration, and rubbing), pH levels, and GSM (grams per square meter). Results revealed that the upcycled denim performed well in terms of color retention, with post-treatment ratings of 4–5 (on a 5-point scale) across acid/alkaline perspiration and washing tests, compared to pre-treatment values of 3–4. Tearing strength improved by 14% in the warp direction (from 17.2 N to 19.6 N) and 28% in the weft direction (from 62 N to 79.8 N), which indicated improved durability. The pH remained within safe ranges (7.2 post-wash), and GSM changes were minimal (498 to 484.6), preserving fabric integrity. Visual assessments confirmed restored aesthetic appeal, while cost analysis pointed to practical industrial use at \$1.89 per unit. By integrating water-saving and low-energy processes, this work proposes a scalable framework to prolong the lifecycle of knit denim, mitigate textile waste, and promote sustainable circular fashion practices.

The findings highlight the possibility of combining cold bleaching with enzymatic treatments to balance sustainability with market competitiveness, offering effective solutions for the denim industry.

### **1. Introduction:**

The fashion industry is responsible for 10% of global carbon emissions and 20% of wastewater production; in fact, it's one of the most polluting industries, surpassing the combined emissions of international aviation and maritime shipping (Herrmann, 2017; Shedlock, 2023). The fashion and textile industry is ranked among the top resource-intensive industries as well. It requires vast quantities of water, energy, chemicals, and land, which lead to serious environmental issues like pollution and waste (Boone, 2009; Global Fashion Agenda & The Boston Consulting Group, 2017; Hiller Connell & Kozar, 2017; Remy et al., 2016; Todeschini et al., 2020). The global textile industry generates around 92 million tons of textile waste per year, a large portion of which either gets dumped in landfills or burned (Herrmann, 2017). It is projected that more than 150 million tonnes of clothing will be landfilled or incinerated by 2050. The industry is projected to use 26% of the global carbon budget by 2050 if the current linear business model, production-consumption, will be unchanged (MacArthur, 2023). This not only adds to environmental pollution but also results in the loss of valuable resources, such as water, energy, and human labor, that are used all over the production process (Todeschini et al., 2020).

Denim is one of the most popular fashion fabrics, as it is worn by kids to adults, the rich to the modest, and every corner of society. The global denim jeans market reached 3.1 billion pairs in 2022 and is projected to exceed 3.46 billion pairs by 2026, reflecting a compound annual growth rate (CAGR) of 3.8% (Statista, 2023). One of the key reasons behind denim's popularity, its impressive durability and long-lasting nature. Despite being recognized for their durability, denim products are exemplary of the systemic inefficiencies inherent in contemporary linear production-consumption systems. Premature obsolescence is continued by current practices as garments are being discarded long before their functional or aesthetic utility is exhausted (Niinimäki et al., 2020; Sandin & Peters, 2018). It has been reported that 85–90% of denim products are disposed of in landfills or through incineration within 2–4 years of purchase, which shows a real gap between material potential and utilization (Sandin & Peters, 2018). This underutilization is exacerbated by fast fashion dynamics, where garments are overproduced and undervalued (Bick et al., 2018). Furthermore, the environmental costs of denim—such as 10,000 liters of water being consumed per pair of jeans during production—are rendered indefensible when such products are not fully utilized (Alliance, 2023). To address this problem, ideas of circular economy principles, including design for prolonged existence and scalable recycling systems, have been proposed as critical interventions (Niinimäki et al., 2020).

The circular fashion idea is one of the best ways to mitigate denim's environmental impact by adopting strategies like reusing, recycling, and upcycling approaches. Strategies for reusing clothes, such as resale platforms and clothing rental programs, have been shown to extend the lifespan of garments. When utilization is doubled, carbon emissions are reduced by as much as 44% (Herrmann, 2017). Similarly, recycling methods like mechanical shredding and chemical fiber regeneration are being developed to recover cotton from post-consumer denim, although challenges like fiber blending and chemical contamination persist (Sandin & Peters, 2018). Upcycling, which converts wasted denim into high-value products (e.g., accessories or building insulation), has been demonstrated to divert textile waste from landfills while retaining material value (Cho et al., 2023).

Fashion brands have increasingly implemented circular techniques to deal with denim waste. For instance, reuse initiatives such as Levi's Tailor Shop repair services and Mud Jeans' lease-a-jean model have been tested to extend product lifespans; yet, these initiatives often face difficulties due to low consumer participation (Costello & Reddy, 2020). Circular fashion campaigns, like Patagonia's Worn Wear program, which turns discarded denim into new goods, show creative waste valorization but struggle with commercial viability at scale (Bick et al., 2018). By encouraging consumers to return used clothing especially denim, for recycling or resale, H&M launched its Garment Collecting program in 2013, collecting over 29,000 tons of textiles globally by 2022 (H&M Group, 2022). The brand has also collaborated with Circulose® (a recycled cellulose fiber made from denim waste) to integrate 20% post-consumer recycled content into new denim collections, but scalability is still limited by a lack of recycling infrastructure (H&M Group, 2022; Herrmann, 2017). Similarly, H&M's collaboration with Loooper Textile Co. seeks to chemically recycle blended denim into new fibers, but technical challenges prevent commercial feasibility. While technological obstacles still exist because of fiber blends, recycling initiatives like H&M's in-store clothing collection campaigns and partnerships with recycling innovators like Renewcell seek to close the denim production loop (Halliday & Dolva, 2025). Beyond recycling, policy-driven initiatives like the EU Textile Strategy 2030 mandate brands to design for durability and fund recycling systems, while voluntary coalitions like The Fashion Pact (signed by brands like Gucci and Zara) pledge to achieve 100% circularity by 2050 (European Commission, 2022) (Keulen, 2024).

Annually in Bangladesh, approximately 600,000 tons of textile waste are generated, most of which is pre-consumer fabric scraps and defective garments from factories, with limited post-consumer recycling infrastructure (Shahrul Islam, 2024). Although in the countries where they have their own retail outlets, some foreign fashion companies like Patagonia, Levi's and H&M do collect previously used clothing items at discount while having them repaired and resold, there are minimal steps taken by the global or

even local brands to prolong product life cycle through similar reuse strategies in manufacturing nations such as Bangladesh (Seo & Jin, 2024). Against this backdrop, this study proposes an innovative reuse framework for pre-owned knit denim pants that integrates cold bleaching, dry processing, bio-polishing, and softening processes to minimize water consumption, eliminate wastewater discharge, and reduce energy use. This strategy attempts to promote scalable, low-impact solutions for Bangladesh's textile waste crisis while aligning with global circular fashion imperatives.

## **2. Literature Review:**

Modern-day customers measure products according to their durability, and this applies to all types of people. Denim production has taken a drastic turn towards environmental friendliness since people want the least possible impact on the climate and society (Muthu, 2017). The demand for denim garments is growing day by day, which involves rising textile waste. Denim production, involving processes like cotton cultivation, dyeing, finishing, and chemical use, significantly impacts local ecosystems and freshwater sources due to high water consumption (Sofronova, 2024). Due to the excessive variety and fashion in denim, the tendency to adopt new fashions creates more textile waste. Denim is manufactured in such large quantities that it is discarded at an equivalent magnitude and either incinerated or deposited in landfills (Neema Tindwa, 2019). Also estimating that textile waste nearly occupies 5% of the total landfill (Muthu, 2017). Most debate focuses on the problem of used garments, which are landfilled in the environment and become waste. Nowadays, the apparel industry is linear, where garments are discarded after consumption, rather than circular, where it involves recycling (Aus et al., 2021; Neema Tindwa, 2019). Fashion and textile companies have agreed to adopt circular methods to decrease the adverse effects on the environment, emphasizing ecologically sustainable materials and thinking of new strategies for product development and production stages to promote circularity. Sustainability mainly indicates the ability to use resources for a prolonged period without inducing any bad effect on future generations, targeting the reuse of unwanted materials for long-term use (SÜNTER EROGLU, 2023). Sustainability and recycling are the new trends in today's world, as all global apparel companies and consumers are showing their support for this cause (Muthu, 2017).

Many researchers are looking for feasible methods for converting textile waste into valuable products (Cho et al., 2023; Joo et al., 2022). An approach to sustainability called 'Upcycling' is gaining more popularity day by day. Over the past few decades, several scholars have explored upcycling as an alternate solution to reducing textile waste from landfills. The products often lose their acceptability to consumers for reasons like wear and tear damage, ill-fitting, and fashion disasters. In those cases, materials that are of good quality can be upcycled and used again, and they can also be sold to poorer countries with a better need for such clothing (Muthu, 2017). Upcycling is the process of converting

textile products that have lost their service life into the same or better-quality products (Pandit et al., 2018).

The constantly increasing number of proclamations on upcycling in multiple subject areas also bears the fact that the idea of upcycling has gained more approval from several business specialists, research workers, artisans, and textile enthusiasts in recent years (Sung, 2015). ELV Denim, a London brand, uses upcycling to transform unwanted jeans into better ones. They collaborate with Outnet to create an upcycled collection from their unsold stock (Design & Short, 2024).

During the last decade, experts have started surveying fashion upcycling as a feasible solution to diminish denim waste as a form of landfill. Where the execution of upcycling in the case of post-use disposal of types of denim is concerned, the users gave away or abandoned unwanted denim garments to housework, relatives, friends, and charities, while less than 40 percent of them were upcycled into wearable outfits and accessories with a few changes. Very few respondents have used left-over denim for making home appliances, decorative pieces, or utility articles (Tomer et al., 2021).

According to a study, remodeled old denim is collected, assembled, and modified in regional retail by cleansing, decolorizing, reprinting, coloring, knitting, and finishing. They assessed the quality of freshly redeveloped denim based on outward presentation and profitability (Teli et al., 2014). However, they did not conduct any trials to determine the ultimate potential of the refabricated denim. Nashwa El Shafei, in his studies, cited many different patterns and procedures for remodeling denim (El Shafei, 2020). Nonetheless, implementation of these decorative procedures can be time-consuming and not suitable for application on an industrial basis, they are rather apt for a smaller-scale production. There is another concern in this study is sustainability. Pavlova uses textile waste from the sewing section to discover boutique denim by upcycling. This process included model selection, design making, comparing, trimming, and developing products (Pavlova, 2021). Nevertheless, it required more testing to be used commercially. Remembering the need for immense effort in categorizing and fabricating, four easy techniques of upcycling are accepted, as it would mean not having to remodel or disintegrate the denim garments. These are- cold bleaching, dry processing, bio-polishing, and softening. There are many techniques for denim cleaning, like enzymatic washing, bleaching, acid washing, normal washing, stone washing, etc. Applying cold bleaching selectively will minimize and decolorize that part, making the denim white. Biopolishing is a procedure designed to eliminate projecting fibers and decrease hairiness, which leads to textiles with a velvety, smooth texture, vivid colors, and a softened fabric feel (Ikbal et al., 2024). Applying bio-polishing agents improves denim standards, but its hairiness remains intact, which can be compensated by pouring softener to make the denim exterior smooth and comfortable to touch (Huang et al., 2025). This continuous checking of the steps can also help to find

out the end fitness of this recently upcycled denim. With the desirable outcome, the life expectancy of these upcycled denims will therefore be improved, while decreasing the scope for substantial debris production. These methods are budget-friendly and easy to put into application on a commercial basis, and they will also result in benefits from the manufacture and product(Pavlova, 2021).

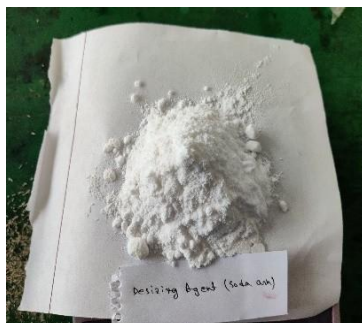
### **3.Experimental Details:**

**3.1 Materials:** A single pair of knit denim pant that had been worn for more than a year.



**Figure: 3.1.1**

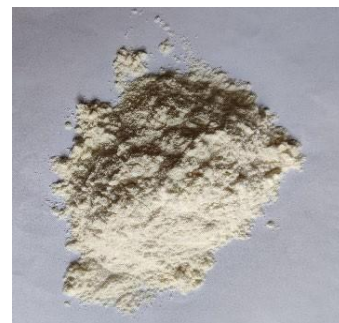
For this study, Soda ash (to create an alkaline medium to remove any additive pigment color), detergent (to remove impurities like dirt, dust, and stains and to clean the garments properly), and bleaching powder  $[Ca(OCl)Cl]$ -to decolorize fabric were used. In addition, PP Spray was used to create a bright effect and fade color in specific areas of garments along with biopolishing agent to improve the quality of the fabric by reducing excessive facial hair and softener to make the garment's surface soft and silky.



**Fig 3.1.2: Soda Ash**



**Fig 3.1.3: Detergent**



**Fig3.1.4: Bleaching Powder**



**Fig 3.1.5: PP Spray**



**Fig 3.1.6: Biopolishing Agent**

**For this research,** electronics precision balance to weigh various chemicals, garments Washing machine to wash fabric with the help of stone and produce an effect on denim jeans, laboratory boiler machines were used. Furthermore, Hydro extractor machine to extracts excess water from fabric and tumble dryer to dry wet fabric were used as well.



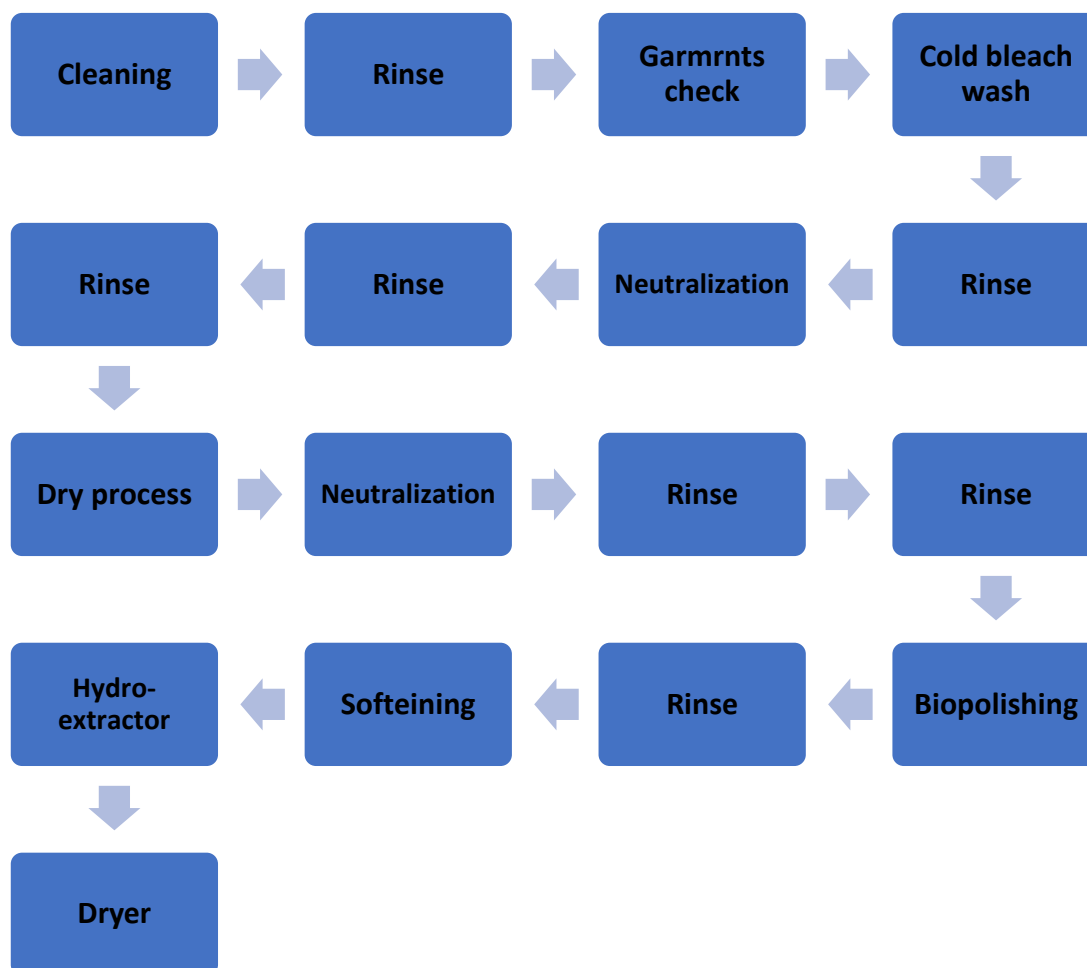
**Fig 3.1.7: Garments Washing Machine**



**Fig 3.1.8: Laboratory Tumble Dryer**

### **3.2 Methods:**

Process Flow Chart:

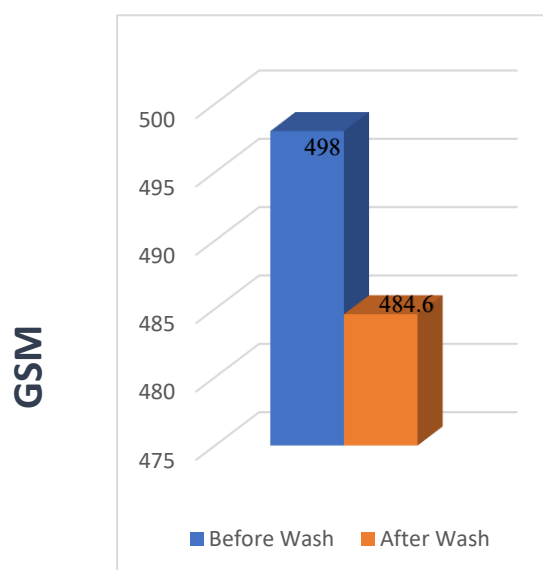


Two different methods were used to upcycle the collected pairs of denim pant. For a comparatively darker shade, Sample-1 was selected for partial bleaching and tinting. And overdyeing was conducted on Sample-2 as its color was extensively faded due to overuse.

As this denim pant was old, it was required to clean it thoroughly. At first, 18g (1g/L) Soda Ash ( $\text{Na}_2\text{CO}_3$ ) and 18g(1g/L) detergent were dissolved in 18litre water and washed the sample at 60°C for 6 minutes which helped to remove impurities, dirt, dust, stains, and unwanted color spots. Then it was rinsed at 25°C with the exact amount of water for 2 minutes. After that, the cold bleaching method was applied which involved washing and bleaching the sample with the same amount of 18liter of water for 6 minutes at 27°C which was followed by rinsing sample as like the previous process. For the neutralization process, 36g (2g/L of water) sodium metabisulfite was added to 18liter water and the sample was washed for 5 minutes at 45°C. At this point, the specimen was rinsed 2 times like the

previous process. As moving to the drying process, the whiskering process was developed and the sample was scrubbed over the prepared pattern with scrapping paper (500 grade) to get the whiskered effect. PP spray (5 gm/L) was applied on the blasting area followed by the repetition of the neutralization process along with two times rinsing. Next, bio-polishing was done by using a bio-polishing agent of 18 gm at 25°C for 2 minutes which later followed by rinsing the sample for 2 minutes. At this point, the sample was washed with a 90 ml (5 ml/L) cationic softener at a temperature of 30°C for 3 minutes and rinsed for 3 minutes. At last, the hydro extractor machine was used to remove the excess water from the washed sample which was running for 5 minutes. Finally, the specimen was dried in the dryer at 70°C for 35 minutes. For this whole process, the calculated cost is \$1.89, according to the factory experts.

**4. Results and Discussion:** A required portion of the specimen was cut with a GSM cutter machine and then measured in an electric balance according to ASTM D 3766 method of standards.

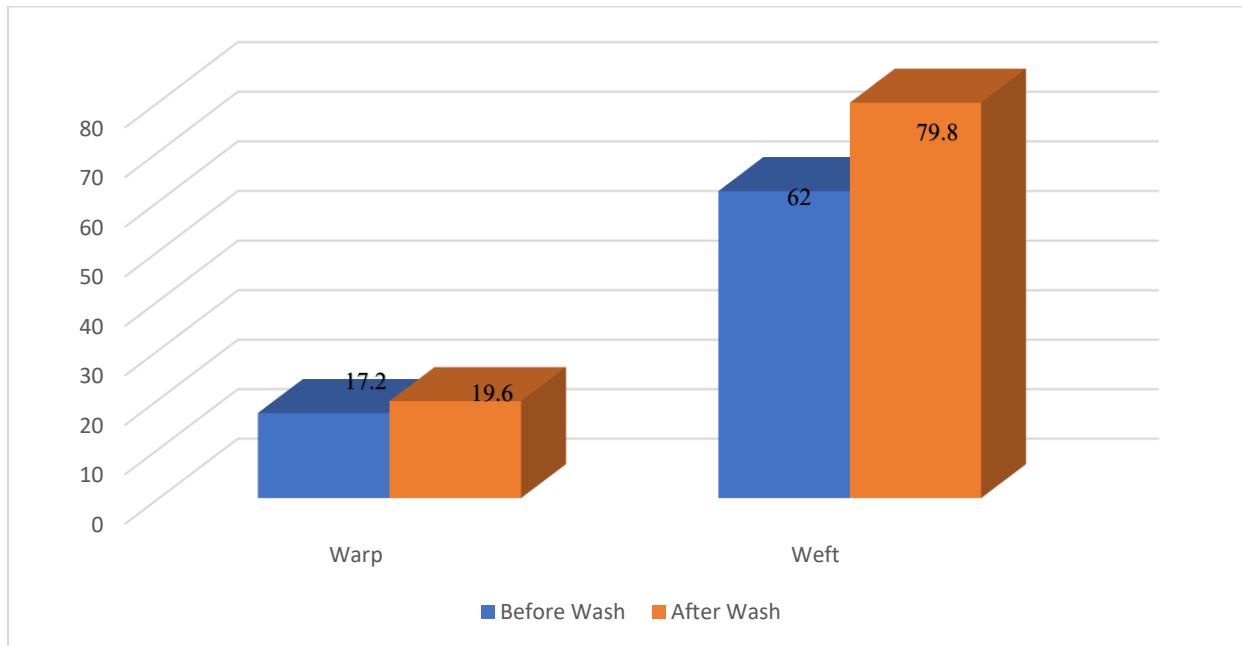


**Figure 4.0: Graphical representation of change in GSM**

Two data points were taken: one was before the wash, which was 498 GSM, and the other was after the wash, which was 484.6 GSM, where GSM was tested on the faded portion and found slightly below the original value.

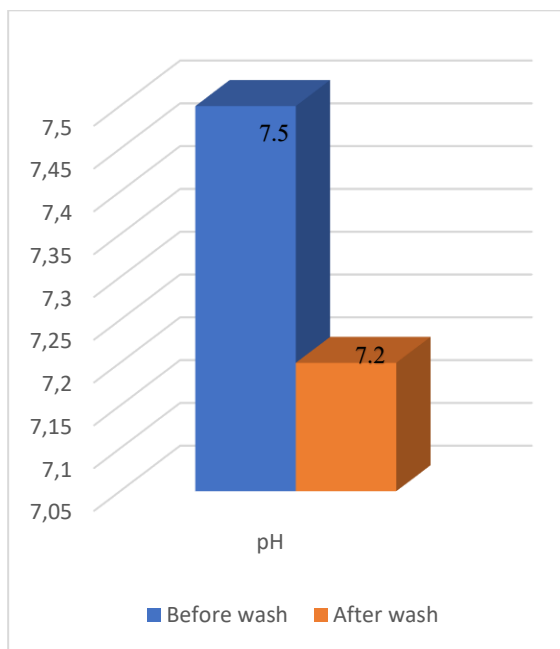
**4.1 Tearing strength:** The sample was tested for its tearing strength, color fastness to rubbing, color fastness to wash, color fastness to perspiration, and pH test was done for data collection and analysis. Tearing strength test was done to test the resistance of the sample fabric to a sudden force applied to it,

which was conducted according to EN ISO 13937-2:20 by using Elmater tear testing equipment. This test was directed at a two-directional warp and weft. The result of the before-wash and after-wash wash is 17.2 N & 19.6 N in the warp direction. On the other hand, in the weft direction, the result is 62 & 79.8 N which represents that after washing, the sample showed excellent strength in both warp and weft direction.



**Figure 4.1.1: Graphical representation of sample fabric's resistance to tearing**

After washing the sample, the pH level was found within the acceptance range which was 7.5 before the wash and 7.2 after the wash. If pH was not at an acceptable level, it could be carcinogenic.



**Figure 4.1.2: Graphical representation of pH Test**

**4.2 Color fastness to wash:** Color fastness to wash was conducted according to EN ISO 105 to determine the resistance of the fabric to change color under normal household washing. The result revealed that the sample’s color fastness to wash was satisfactory which indicates that this sample would be able to withstand color regardless of a satisfactory number of household washings.

Sample Name	Color change	Color Staining On					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Before Wash	4	4-5	3-4	4	4-5	4	4-5
After Wash	4	4-5	4-5	4	4-5	4-5	4

Rating System- 5 (Excellent), 4 (Good), 3 (Fair), 2 (Poor), 1 (Very Poor)

**Table 4.2.1: Color Fastness to washing**

**4.3 Color fastness to perspiration:** The perspiration was conducted according to EN ISO 105 E04 for which a sample size (10cm x 4cm) taken and sewn with a same size multi fiber cut piece which was soaked in both acid and alkaline solution and then, subjected to a fixed mechanical pressure and later

dried slowly at an elevated temperature and tested with grey scale. Color fastness to perspiration test just creates a simulated situation of human sweating phenomenon to test the specimen color fastness against human sweating. Color fastness to perspiration for the sample is found to be alkaline excellent in both acid and mediums, indicating that samples will have excellent color fastness towards humane towards sweating during long-term use.

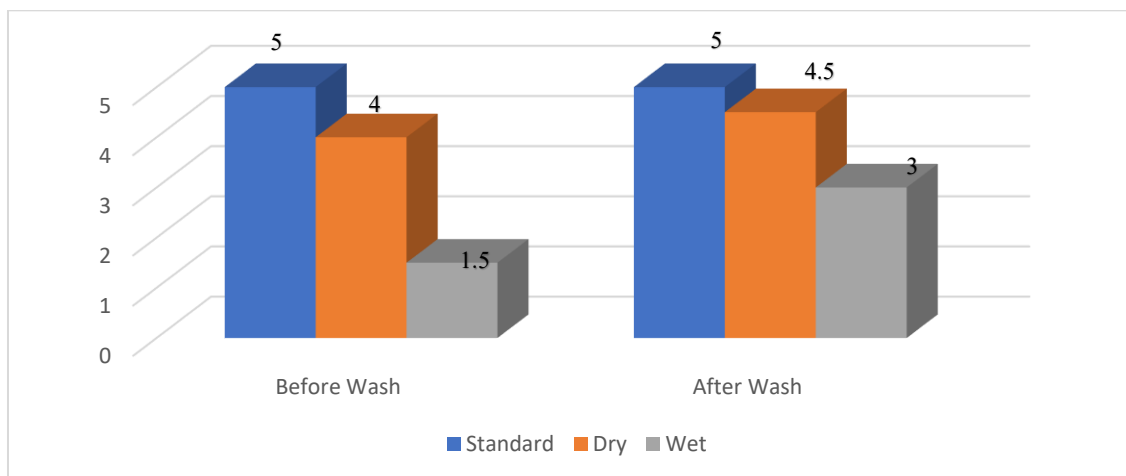
Sample Name	Color change	Color Staining On					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Before wash	4	4-5	3-4	4	4-5	4	4-5
After wash	4	4-5	4-5	4-5	4-5	4-5	4-5
Rating System- 5 (Excellent), 4 (Good), 3 (Fair), 2 (Poor), 1 (Very Poor)							

**Table 4.3.1: Color Fastness to Perspiration in Acid Medium**

Sample Name	Color change	Color Staining On					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Before wash	4	4-5	3-4	4	4-5	4	4
After wash	4	4-5	4-5	4-5	4-5	4-5	4-5
Rating System- 5 (Excellent), 4 (Good), 3 (Fair), 2 (Poor), 1 (Very Poor)							

**Table 4.3.2: Color Fastness to Perspiration in Alkaline Medium**

**4.4 Color fastness to rubbing:** Color fastness to rubbing was conducted to understand the resistance of color from the surface of the sample fabric to staining on other colored fabric. The standard testing method ISO 105-X12-2016 was followed. Color fastness to rubbing was found satisfactory on samples after testing. This indicates that denim pants retain their color well even after washing.



**Figure 4.4.1: Graphical representation of Color Fastness to Rubbing**

Sample Name	Standard	Dry	Wet
Before Wash	5	4	1.5
After Wash	5	4.5	3

**Table 4.4.1: Color Fastness to Rubbing**

**5. Visual Change:**



**Figure 5.0: Visual Change of Sample**

## **6. Conclusion:**

The study was designed to determine how the upcycling process can be used to reuse denim pant and the effect of tearing strength, color fastness to wash, rubbing, and perspiration on washed garments for sustainable development.

- The most obvious finding of this study is there is a significant visual change between before and after washing garment.
- The after-wash sample demonstrates a commendable pH level and color fastness results to different mediums.
- The research further analysis the tearing strength of the sample after upcycling process.
- This project is the first comprehensive investigation to see the effect of cold bleaching, drying, bio-polishing, and softening agent on a used denim which paves the way for future research for a large-scale industrial manufacturing unit.

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