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Measuring physical garment durability: An assessment of 47 T-shirts

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Abstract: Designing for durability, both physical and emotional, has been identified as non-negotiable in the battle against overconsumption, underutilization and the devasting effects of climate change. There is currently no consistent method of measuring physical garment durability or the ability to compare garments on the market. This study presents a reproducible and novel method for measuring and ranking the physical durability of 47 t-shirts. Multiple durability factors were used to modulate the ranking whereas previous studies have only reported on single factors to evaluate durability. The benchmarking results reveal that price cannot be used as an indicator of durability and that fabric composition does influence the physical durability of a t-shirt. The garments in this study were donated by the signatories of the Waste Resource Action Programme's (WRAP) Textile 2030 initiative as part of their strategy to reduce the environmental impact of UK fashion.

Introduction

In the UK alone, the physical waste created by the fashion industry is excessive. 779,000 tonnes of textile waste were reportedly sent to landfill or for incineration in 2021, with 72% of this coming through the kerbside residual waste stream (WRAP, 2024). Furthermore, by 2030, global apparel consumption is projected to rise by 63% to 102 million tonnes (Casado et al., 2024), and in turn inflating the future textile waste stream. Increased garment durability has been cited as a lifespan extension strategy to increase utilisation, producing garments which are designed to last longer, and reduce the number of garments produced and ultimately generate less waste. A physically durable garment can be defined as one that will remain functional without exhibiting any degradation or damage in comparison to a similar garment (Annis, 2012). An emotionally durable garment is one that the user has a connection to, it remains relevant and desirable to the wearer (Chapman, 2005). For the purpose of this study, physical durability will be the main focus with the aim of developing a consistent and adoptable method to measure physical durability which currently does not exist.

Eco-design for Sustainable Products Regulation (ESPR) and Extended Producer Responsibility (EPR) schemes have been suggested and will be implemented across Europe and the UK which will legally require brands to declare a garment's durability credentials. There is currently no uniform method to measure the physical durability of a garment. To increase the durability on the market as well as meet the criterion being laid out in legislation, a method of measuring physical durability must first be devised. Through assessing the physical factors which affect the lifespan of a specific garment type, a t-shirt in this case, a testing protocol and benchmarking framework can be developed. These tools can be used to moderate the garments being placed on the market to ensure durability as a design core has been considered and that each product can withstand multiple lifetimes within a circular economy (Sun et al., 2021).

Methodology

This study aimed to create a tool to measure and compare the durability of T-shirts to further understand how design for durability can be

Test	Test Standard
Bursting Strength	ASTM D3787
Pilling	BS EN ISO 12945-2:2020
Spirality	BS ISO 16322-3:2021
Dimensional Stability	BS EN ISO 5077:2008
Visual Assessment	Modified ISO 15487

Table 1. Summary of test methods used to measure garment durability.

used as a lifespan extension strategy. 47 t-shirts in total, 24 Men's, 23 women's, from UK clothing brands were procured in the spring/summer of 2024. A testing protocol to measure physical durability was devised based on the main modes of failure for a t-shirt (Cooper & Claxton, 2022) . Table 1 displays the test methods and standards used to test the performance of the garments.

All the t-shirts were washed in a domestic washing machine and tumble dried 50 times. The washing and drying process can significantly damage a piece of clothing (Card et al., 2006; McQueen et al., 2017) and therefore, must be accounted for when assessing physical durability. The t-shirts were removed and assessed at wash intervals 5, 15, 30 and 50. Garments were reviewed under D65 illuminant while six factors were assessed including, pilling, surface disruption, colour fading, colour change, component damage, and visual stability. A graded system was used to assess these factors, Grade 5 equaling no change, while Grade 1 equates to severe change. This system is based on ISO 15487 – Method for assessing appearance of apparel and other textile end products after domestic washing and drying (British Standards Institution, 2018). This standard outlines a method of assessing garments after washing, however it is not specifically investigating the durability of the garment. Therefore, this method has been used as a building block to create a 6-aspect assessment process focusing on physical durability only. The grades of the six aspects at the 50th wash interval have been added together to create a visual assessment score. 30 is the highest score and indicates excellent visual garment durability, 0 is the lowest and indicates extremely poor visual garment durability.

Dimensional Stability has been condensed into an overall score out of 8 based on the measurements taken across 2 measurement points at each of the 4 intervals. 8 is the highest score and indicates excellent garment dimensional stability, 0 is the lowest and indicates extremely poor dimensional stability.

All results were fed into the durability benchmark system where garments can be directly compared and ranked based on overall physical durability. The benchmarking system is a method of ranking the garments based on the level of importance for each test, thresholds, and the actual results of all the tests conducted as listed in Table 1. Other studies have attempted to create a method of measuring and ranking the durability of a garment (Benkirane et al., 2022; Ghaani Farashahi et al., 2018) however little information is shared about the method used to judge how physically durable a garment is and there is currently no agreed method. This iterative method uses a comprehensive approach that uses a combination of results to dictate how durable a t-shirt is as opposed to other studies which only compare single tests (Badgett, 2019; Wakes et al., 2020).

Thresholds have been developed for each test which modulate how the garments move through the benchmark. Each test has been allocated a level of importance, with the most important test having the most weight on where the garment is placed in the benchmark and the least important having less of an impact.

The ranking process was automated using the process explained above using the Excel 'Custom Sort' function by adding levels of rules. Figure 1 provides the framework for the ranking process which can be used for all garment categories regardless of the durability factors that need to be considered in the ranking process. Table 2 displays the results once the benchmarking framework has been applied.
The tests are ordered by level of importance, pilling being the most important and bursting strength being the least, the threshold for each test can be found at the top of Table 1. Thresholds have been developed using existing industry standards (pilling and spirality) and the mean average (visual assessment, dimensional stability, and bursting strength). The results which did not meet the basic threshold have been highlighted in red. All samples have been coded to keep all brands anonymous, codes use the letters TSW (T-shirt women's) and TSM (T-shirt men's) followed by a randomised number.

Pilling has been found to be the main reason why consumers dispose of a t-shirt, while the typical pass rate for the dry pill test in industry is a Grade 3-4, it is not uncommon for a Grade 2-3 to be commercially accepted (Cooper & Claxton, 2022) hence why the threshold for pilling is a Grade 2-3 (2.5). Anything below a Grade 2-3 could be seen by a consumer as a reason to stop wearing the t-shirt. Visual assessment is weighted the 2nd most important

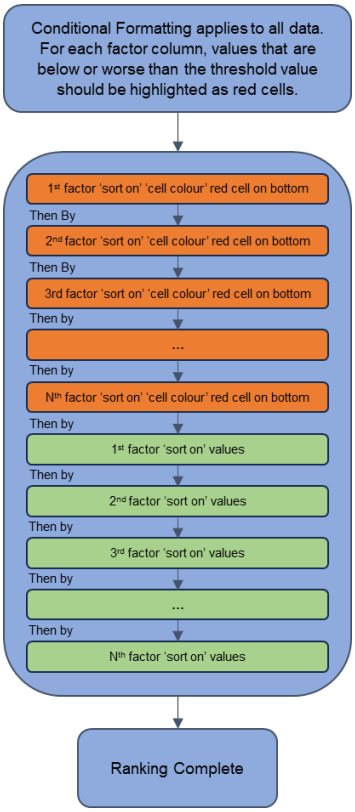

Figure 1. Automated step by step benchmarking process

test, this assessment is a grade representation of how the t-shirt changes over time considering colour fading, texture change and visual stability, all aspects cited as reasons for disposal (Cooper & Claxton, 2022). If by 50 washes a low score is observed, it is likely that a consumer would not continue to wear the garment due to its appearance regardless of whether it is still technically functional. It is this aspect where emotional durability must be considered. Dimensional Stability has been placed as the 3rd most important followed by Spirality. Changes to shape and fit have been cited as reasons to no longer wear a t-shirt (WRAP, 2022). Bursting strength has been placed as the least important, although there are tight fitting styles available, many t-shirt styles have a looser fit. On the styles which are tighter fitting if the consumer is wearing the appropriate size it is unlikely that enough force will be placed on the fabric for the fabric breaking to be a common issue.

Results and Discussion

There is a wide variation in the results across the 47 t-shirt samples. Pilling results range from a Grade 5, indicating no change down to a Grade 1 which implies severe pilling present. Most of the samples achieved an above threshold result, with only 10 samples falling below the Grade 2-3 threshold. Interestingly, 80% of the samples which did not reach the threshold result for pilling also did not reach the threshold for visual assessment. The final scores for visual assessment ranged from 27.5 down to 9 out of 30. The average final score is 19 out of 30. Scores for dimensional stability spanned the full range from a score of 0 to 8. Some garments which exhibited excellent dimensional stability (samples 25 – 30) ranked lower down on the benchmark due to the below average visual assessment score. Spirality results also varied from 1.2%, hardly any change, to 18.2%. 8 samples exhibited double or more than the industry standard of 5% spirality after 5 wash cycles. Finally, results range from 156N up to 598N for bursting strength. Only 18 out of the 47 samples achieved an above threshold result.

A Pearson correlation coefficient was used to assess the linear relationship and significance between the different variables assessed, several significant correlations were found both at the 0.5 and 0.01 confidence level. $p<0.05$ is significant, and correlation was identified by calculating Pearson's r, where $r(45)<0.5$ represents a strong correlation and $r(45)<0.7$ a very strong correlation. A strong positive correlation between the pilling and visual assessment was found $r(45)=0.608$, $p=<0.001$. This infers that a garment which scores well on the dry pilling test will also score well for visual assessment. A small positive correlation was observed between visual assessment and bursting strength at the 0.5 significance level $r(45)=0.289$, $p=0.048$. Furthermore, dimensional stability and spirality exhibit a negative correlation $r(45)=-0.320$, $p=0.028$. This correlation is not surprising considering both are wash related aspects and for spirality the higher the number the worse the result as opposed to dimensional stability where the higher the number the better the result. Two other correlations were observed including a positive correlation between bursting strength and dimensional stability $r(45)=0.304$, $p=0.038$ and a negative correlation at the 0.01 significant level between spirality and bursting strength, $r(45)=-0.406$, $p=0.005$.

				Test Result Thresholds				
				Grade 2-3	19	5	5%	287N
Rank	Retail Price	Fabric Composition	External Code	Pilling (7000revs)	Visual Assessment (Final Grade)	Dimensional Stability Score	Spirality (%)	Bursting Strength (N)
1	£28	87% Polyamide, 13% Elastane	TSW7	5	25.5	7	4.1	425.5
2	£35	94% Polyester, 6% Elastane	TSM36	5	24.5	8	1.2	421.7
3	£12	100% Polyester	TSM15	5	24.5	5	1.3	598.3
4	£10	100% Cotton	TSW8	4	21.5	8	2.5	287.4
5	£32	100% Cotton	TSM6	3	19.5	8	3.5	420.6
6	£10	96% Cotton, 4% Elastane	TSM25	4	22.5	5	3.8	204.6
7	£12	70% Cotton, 30% Polyester	TSM38	4	22	4	2.5	232.4
8	£24.99	100% Cotton	TSM8	4	20	4	3.5	260.3
9	£5	60% Cotton, 40% Polyester	TSW20	4	19.5	4	1.9	233.6
10	£8	100% Cotton	TSW43	4	19	4	4.6	241.8
11	£35	75% Cotton, 25% Polyester	TSW28	4.5	21	6	6.3	336.9
12	£24	75% Polyamide, 25% Elastane	TSW39	5	27.5	8	7.9	156
13	£8	100% Cotton	TSM23	3.5	19.5	6	5.6	244.3
14	£18	100% Polyester	TSM12	5	26.5	3	2.4	485.3
15	£4	95% Cotton, 5% Elastane	TSW4	4	20	1	1.4	244.7
16	£20	100% Cotton	TSM11	3.5	21	2	4	268.2
17	£7.50	100% Cotton	TSM28	3	19	1	6.3	296.4
18	£15	100% Cotton	TSM14	4	21.5	1	9.1	264.4
19	£12	100% Cotton	TSW47	3.5	24	0	12.8	264.8
20	£9	48% Cotton, 47% Modal, 5% Elastane	TSW34	3.5	23	3	7.6	271.4
21	£7	100% Cotton	TSM33	3.5	19.5	3	5.8	254.4
22	£14.99	100% Cotton	TSM9	3.5	19	3	11.9	242.4
23	£5	100% Cotton	TSM35	3	20.5	1	12.7	270.9
24	£12	100% Cotton	TSW45	3	19	3	5.3	274.7
25	£31.99	95% Polyester, 5% Elastane	TSM34	4	18	8	3.5	347.7
26	£55	100% Cotton	TSM1	3.5	15.5	8	4.1	303.0
27	£16	50% Polyester, 50% Viscose	TSW30	3	17.5	8	4	347.6
28	£395	100% Cotton	TSM40	5	18	6	4.3	205.1
29	£18	100% Cotton	TSM17	3	16.5	8	5.8	451.6
30	£28	92% Modal, 8% Elastane	TSW26	3	17	8	18.2	206.8
31	£28	100% Cotton	TSW23	4	17.5	1	3.7	404.4
32	£5	100% Cotton	TSM29	3	18.5	2	4.1	303.5
33	£6	100% Cotton	TSW36	3	18.5	0	4.6	252.6
34	£8	100% Cotton	TSW40	4.5	16.5	1	10.6	190.6
35	£12.50	95% Cotton, 5% Elastane	TSW10	4	17.5	1	7.8	240.1
36	£8	100% Cotton	TSM19	3.5	17.5	2	11.7	270.1
37	£45	100% Linen	TSW14	3	15.5	0	17	180.7
38	£5	100% Cotton	TSM3	2	19.5	2	1.5	312.9
39	£40	100% Cotton	TSM22	2	20	1	7.7	296.6
40	£10.50	95% Lyocell, 5% Elastane	TSW22	1.5	16.5	8	2.9	206.4
41	£29	68% Bamboo Viscose, 28% Cotton, 4% Elastane	TSM5	1	17.5	4	4.8	180.9
42	£35	100% Cotton	TSM31	2.5	11.5	7	5.3	393.5
43	£16	100% Cotton	TSW38	1	18	4	8.6	308.4
44	£12	100% Cotton	TSW31	2.5	17.5	4	9.1	257.7
45	£42	100% Cotton	TSW3	2	9	0	4.1	189
46	£29	100% Cotton	TSW17	2.5	16.5	1	10.8	186.8
47	£7.99	100% Cotton	TSW18	1.5	15	1	15.1	245

Table 2. Final Benchmarking Results of 47 commercially available T-shirts

The results indicate that the more durable t-shirts have a percentage of synthetic fibers in the composition, including polyester, polyamide, and elastane. 64% of the garments which contain synthetic fibers rank in the top 50% of all the garments tested, while 60% of the top 10 garments contain synthetic fibers.

Cotton or other natural fibers are known to have higher shrinkage issues due to swelling shrinkage (Saville, 1999) which can be exacerbated through tumble drying (Higgins et al., 2003). Therefore, it is not surprising that only 3 out of the 23 garments which did not meet the dimensional stability score threshold, had synthetic fibers in the composition. Aligning with previous research to show that t-shirts with natural fibers are likely to have more shrinkage issues, which has been identified as a reason for disposal (Cooper & Claxton, 2022). There are 29 100% Cotton t-shirts that have been tested. The ranking for these garments ranges from 4th most durable down to the least durable. This suggests that all 100% Cotton single jersey t-shirts cannot be presumed to have a similar performance. Other factors such as fiber quality and processing must be considered. Spearman's rank correlation was used to investigate whether fabric weight and the rank of all 100% cotton t-shirts were correlated. The results indicated that garments which used heavier 100% cotton fabrics ranked higher r(45)=0.442, p=0.016. This suggests that when assessing 100% cotton t-shirts a heavier fabric is likely to be more physically durable. Further investigation into the processing of the cotton should be conducted to explore whether other factors may be contributing to the variation in results such as Open ended versus Ring spun.

Price is commonly used by consumers as an indicator of a durable product (Degenstein et al., 2020). However, the benchmark clearly demonstrates that price cannot be used as an indicator of durability. The most expensive t-shirt priced at £395 was ranked 28th out of 47, while the cheapest at £4 placed 15th. Furthermore, the t-shirt which was ranked the most durable is priced at £28 while the t-shirt which was ranked as the second least durable is priced similarly at £29. Equally, the garment, which is placed last in the benchmarking, after failing to reach the thresholds on every test, cost £7.99. This indicates that there is no correlation between price and garment durability r(45) = -0.95, p=0.527. An expensive t-shirt is not necessary physically durable and likewise with a cheaper counterpart. Therefore, price cannot be used by consumers as a predictor of overall garment durability for a t-shirt.

Conclusions

This study tested 47 t-shirts from various UK brands to a durability testing protocol considering end use. Results were fed into a benchmarking framework to directly compare the physical durability of each t-shirt. This comparison has allowed for observations to be made regarding the properties of the most durable and least durable garments. These observations can be used in research going forward to investigate how to improve the durability of t-shirts on the market. The findings showed that:

- Composition can be used as an indicator of durability. T-shirts which had synthetic fibers in the composition were on average ranked higher.
- Heavier 100% Cotton t-shirts ranked higher on average than lighter 100% Cotton t-shirts.
- Price is not an indicator of durability. Although some more expensive garments ranked highly, some also ranked low down on the benchmark. Furthermore, several of the cheaper t-shirts performed just as well or better than the expensive ones.

Although this paper presents a comprehensive approach to measuring physical durability, it does not address the vital role emotional durability, the concept of a garment being kept and worn due to emotional attachment, must play in utilisation. Further work must be conducted to explore the dynamics of physical and emotional durability.

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