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The Influence of Detergents on the Physical and Mechanical Properties of Clothing Fabrics

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Abstract: Cotton textiles have found wide application in both male and female clothing due to its comfort attributes. It happens to be the most commonly used natural fibre in the world today. But it was found drawbacks for this fabric after the cleaning process is done. The reason for this is because the washing condition, detergent type, and drying condition are all key factors that determine the level of damage. The main objective of this study is to study the influence of commercial laundry detergent on cotton fabrics by carrying out the shrinkage, tensile strength, and tearing strength test. The method that was used for this test is using AATCC test method 135-2004 related to ISO 3759 which dimensional changes of fabrics after home laundering with different amounts of detergents. A washing machine with top loading is used to clean the fabric. The detergent used for this study is in powder and liquid form. These two types of detergents have different approaches toward fabric. All the laundering processes are done with the same washing condition. The experiment was divided into two parts, where measurement was carried out to examine the properties of textile material before the detergent treatment and after the detergent treatment. Then, the fabric characteristics before and after the detergent treatment are determined. According to the result obtained, liquid have tendency to make fabric changed in fabric structure whereby can reduce the fabric strength compared to powder detergent. Due to the concentration of the detergent, the fabric also experiences a decrease in strength. The overall shrinkage test showed a decrease in fabric dimensions after laundering which is in between 2 to 5 percent. The detergent treatment caused the greatest loss of breaking strength for both types of detergents whereby it loss in between 5 to 48 percent. The loss of strength also happened to tearing strength where it loss in between 8 to 44 percent.

Keywords: Cotton Fabric, Detergent, Physical Properties, Mechanical Properties

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1. Introduction

The textile industry plays an important role in any economy for country, trade, and employment, and is rising steadily around the world, especially in developing countries (Majumdar et al., 2020). It can show there is a large consumer involved in this industry. Since the textile industry plays a significant role for people as apparel for daily wear so of course, some issues need to be addressed. For example, the effect when the fabric is washed multiple times when to clean the dirt from it.

Due to their comfort properties such as friendly characteristics, cotton fabrics have found wide use in both male and female wear (Ibrahim & Hassan, 2016). Despite the benefits, dimensional shrinkage for cotton is one of the most famous lacks of these clothes (Yuan et al., 2013). After the cleaning process is done, some fabrics shrink (Azam et al., 2009). It can be categorized as the physical change of fabric. Physical change is a changing in shape and dimension for fabric that can affect the comfort of the consumer from continuously wearing it. Therefore, identification of shrinkage is very necessary to know as the idea of improving the life span of fabric.

Apart from that, the fabric after laundering can also affect the mechanical properties from its initial condition. The example parameter covers in this part such as tensile and tear tests. By identifying those things, the fabric is easy to differentiate from one to another. For example, the fabric has changed in yarn geometry after laundering. It will affect the mechanical properties of fabric after laundering (Zambrano et al., 2020). The effect of loading on the tensile strength of fabrics is very important and has been studied widely by many researchers (Kovar, 2010). Besides, one of the most popular types of failure in textile materials is tearing and its ending their life in many situations (Eryuruk & Kalaoğlu, 2015). Hence, the tensile and tearing strength test for fabric will be conducted during this study.

1.1 Problem Statement

According to a previous by Toshikj & Mangovska (2011), few problems need to be addressed. The methodology does not explain the type of washing machine. Conventional washers have two types of loading, which are top and front loading. It is very important to mention because it affects different approaches towards the fabric. Both two types of washer have a certain influence on fabric (Schlag & Ordonez, 2010). Plus, it also does not explain whether this test follows the *American Association of Textile Chemists and Colourist* (AATCC). This organization has a standard test method for fabric that is related to the *International Organization for Standardization* (ISO). The conducted tests for this study are shrink and colour fastness. For colour fastness test the researchers using an appropriate machine which X-RITE CA 22. The result for dimension stability of this study cannot be identified. Therefore, the test for dimensional stability which shrinkage tests need to revisit.

One of the concerns of cotton material is the shrinkage after laundering (Leverette, 2019). Many people have been exposed to the discomfort of the shrinkage of their clothes during washing. In water, cotton has the property of swelling and it gives an impact for shrinking. Also during spinning, it causes the fabric to shrink due to the mechanical action inside the washing machine. Besides, mechanical properties of the fabric will affect the finishing of the material after laundering as well. Hence it is important to recognize the difference in mechanical behaviour such as break and tear ability of fabric (Zambrano et al., 2020).

The test at this time will be conducted with different parameters. The effect of different detergents for fabric on shrinkage will be covered. Shrinkage is one of dimensional changes which physical change that can occur for fabric after washing. Plus, the fabric also is tested on mechanical properties before and after treatment. Breaking and tearing strength test will cover on mechanical properties. The chosen fabric for this study is cotton. The reason cotton is selected because it is exposed to shrinkage due to the readiness of absorbing water (Jain et al., 2019).

1.2 Objective

This study consists of two main objectives which are to study the shrinkage of selected fabric towards different detergents using a home laundering washing machine and to determine the break and tearing strength ability before and after the treatment for selected fabric.

2. Methodology

2.1 Materials and Equipment

The laundering material and apparatus that will be used in this project are described. It consists of characteristics of the cloth, detergents, and washing machine, electronic scale, fabric marker, and miscellaneous. Table 3.1 shows the detail of this study.

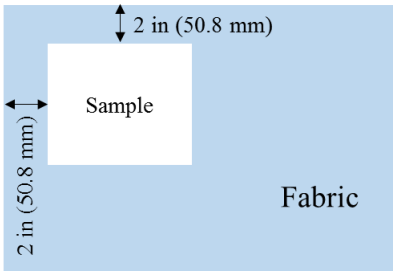
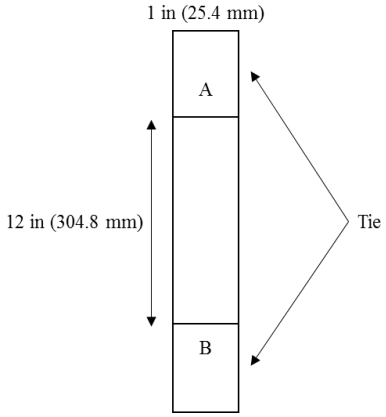
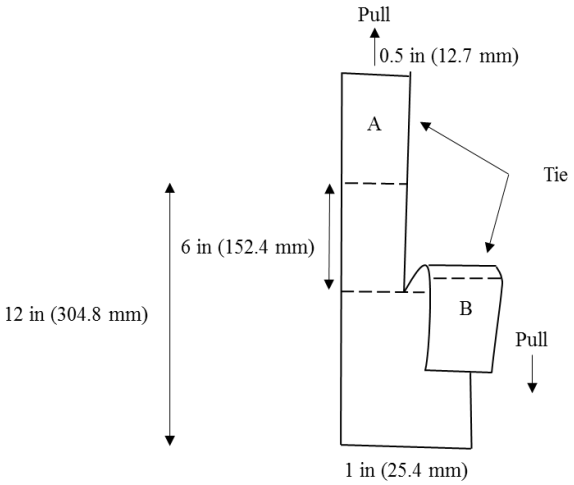
Table 3.1: Material and equipment

Material	Description
Fabric	• Fabrics: Cotton • Structure: Plain weaves • Supplier: Local store
Detergent	• Brand: Dynamo • Types: Powder and liquid • Variant: Perfect clean • Net weight: 2.8 kg • Manufacturers: The Procter and Gamble Company
Washing Machine	• Brand: LG • Model: WF-SP900W • Types: Top loading • Mode: Fully automatic • Weight: 42 kg • Wash load: 9 kg • Manufacturer: LG Electronics
Electronics Scale	• Model: SF-400 • Capacity: 5 kg\ • Battery: 2X AAA • Volt: 1.5 V
Miscellaneous	• Scissor • Ruler • Clothespin • Hook • Bucket • Marble • Fabric Marker

2.2 Dimension Measurement

All experiments conducted for this study required a specific size based on Table 3.2. Three specimens will be taken for each experiment. Each specimen should be taken 2 in (50.8 mm) from the edge of the fabric. It can be seen as shown in the example for the shrinkage test. Figure 3.4 shows the dimension direction of the fabric.

Table 3.2: Size measurement for test

Test	Size
Shrinkage	 10 x 10 in (254 mm)
Tensile	 12 in (304.8 mm) x 1 in (25.4 mm)
Tearing	 12 in (304.8 mm) x 1 in (25.4 mm)

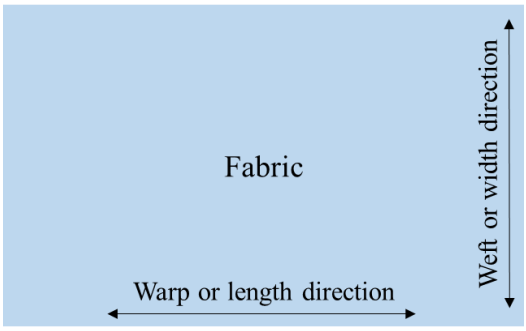


Figure 3.1: Dimension direction of the fabric

2.3 Experiment

In this experiment, the characteristics of the fabric, detergent, and washing method are finalized. A further explanation is stated in Table 3.3.

Table 3.3: Experiment method

Process/Material	Description
Fabric	The selected fabric for this project is cotton. The samples used have the same fabric structure that is the plain weave structure. The fabric will be tested before and after the cleaning process to see how it reacts towards detergent.
Detergent	In this experiment, there are two types of detergents used. The detergent brand was picked from the market randomly. The detergent is in powder and liquid form. For each treatment, the amount of detergent used is 33, 66 and 80 grams for each type of detergent.
Washing Method	Laundry using a conventional automatic washing machine with top loading following the AATCC test method 135-2004 related to ISO 3759. For this experiment, laundering applies to the use of automated washing machines without heat. A normal setting for machine cycle and washing machine conditions without load. The fabric is cleaned to simulate home washing with a total wash load of 1.8 kilograms per cycle for each treatment. The time taken to wash each detergent is 36 minutes. The temperature of water is 27° C $\pm$ 3. Samples were tumble-dried for 6 minutes at a normal setting. Drying at room temperature with hanging in still air.

2.4 Test Method

The test methods that have been used in this project are described. The apparatus for each type of experiment are included in the methods used.

Table 3.4: Test procedure

Test	Procedure
Shrinkage	The apparatus for this test consists of a scissor, ruler, and fabric marker. Wash and let it dry at room temperature. After dry, measure that square. Finally, the fabric shrinkage percentage will be calculated to see the difference from the initial size using Equations 3.1 and 3.2. The negative values represent shrinkage occur on fabric.

$$\Delta L = \frac{l_o - l_i}{l_i} \times 100\% \quad \text{- Equation 3.1}$$

$$\Delta W = \frac{w_o - w_i}{w_i} \times 100\% \quad \text{- Equation 3.2}$$

Where:

ΔL = Percentage of length changes (cm)
l_o = Current length (cm)
l_i = Previous length (cm)
ΔW = Percentage of width changes (cm)
w_o = Current width (cm)
w_i = Previous width (cm)

Tensile

The equipment for this experiment consists of a scissor, ruler, fabric marker, bucket, marble, clothespin, and hook. Tie both ends of fabric to the clothespin. At area A, hang the hook at the cloth hanger. Next, hang the bucket at the other end which area B as a medium to put load. The selected load for this test is a marble. The weight of each bag of marble is 430 grams (4.22 N). Adding the next load with 10 seconds interval until it breaks. Allowing the strain force to act on the sample until it breaks within the area from area A to B. Finally, the loss in tensile strength percentage will be calculated to see the difference from the initial strength using Equations 3.3 and 3.4. The negative values represent break loss occur on fabric.

$$\Delta L = \frac{l_o - l_i}{l_i} \times 100\% \quad \text{- Equation 3.3}$$

$$\Delta W = \frac{w_o - w_i}{w_i} \times 100\% \quad \text{- Equation 3.4}$$

Where:

ΔL = Percentage of strength loss changes in length direction (N)
l_o = Current strength (N)
l_i = Untreated strength (N)
ΔW = Percentage of strength loss changes in width direction (N)
w_o = Current strength (N)
w_i = Untreated strength (N)

Tearing

The equipment for this experiment consists of a scissor, ruler, fabric marker, bucket, marble, clothespin, and hook Tie both ends of fabric to the clothespin. At area A, hang the hook at the cloth hanger. Next, hang the bucket at the other end which area B as a medium to put load. The selected load for this test is a marble. The weight of each bag of marble is 150 grams (1.47 N). Adding the next load with 10 seconds interval until it breaks. Allowing the strain force to act on the sample until it breaks within the area from area A to B. Finally, the loss in tensile strength percentage will be calculated to see the difference from the initial strength using Equations 3.3 and 3.4. The negative values represent break loss occur on fabric.

3. Results and Discussion

3.1 Shrinkage Test

The final results were plotted into graphs to compare the differences in each treatment. These were taken from the average length of the three specimens cut along the warp and weft direction respectively for each sample. Table 3.1 shows the summarized result for this test.

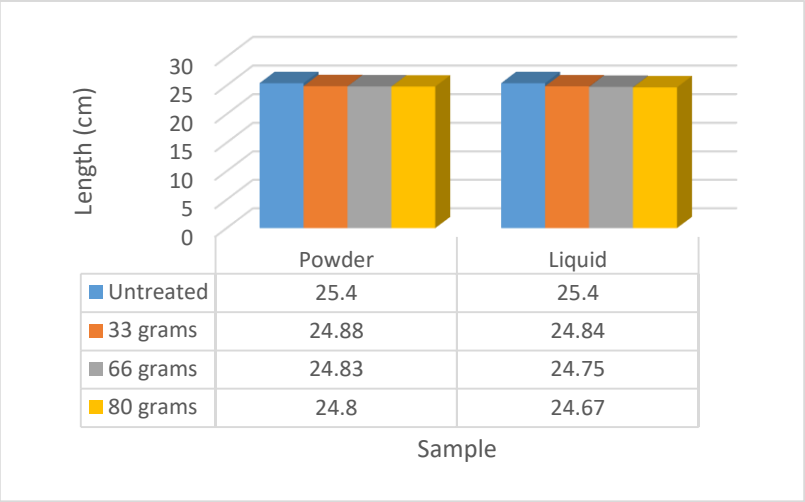
Table 3.1: The summarized result of shrinkage test

a) Powder detergent

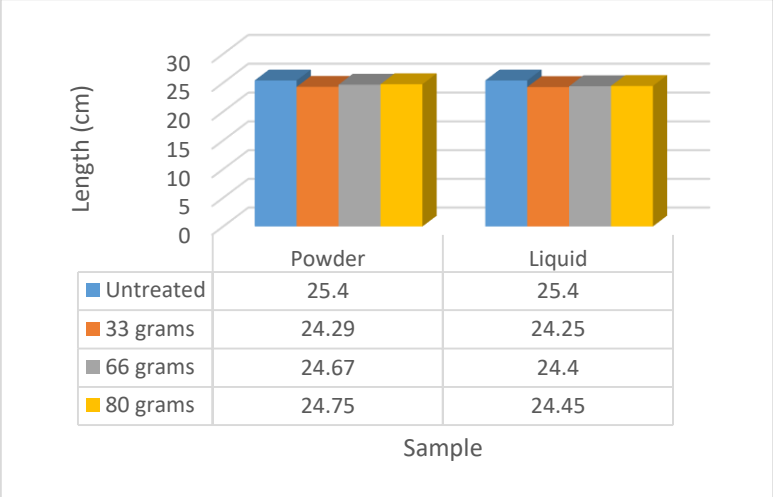
Parameter	33 grams		66 grams		80 grams	
	Warp	Weft	Warp	Weft	Warp	Weft
Maximum (cm)	25.23	24.63	25.10	25.13	24.86	24.97
Minimum (cm)	24.53	24	24.33	24.27	24.57	24.53
Mean (cm)	24.88	24.29	24.83	24.67	24.80	24.75
Percentage of shrink (%)	2.05	4.37	2.24	2.87	2.36	2.56

b) Liquid detergent

Parameter	33 grams		66 grams		80 grams	
	Warp	Weft	Warp	Weft	Warp	Weft
Maximum (cm)	25.45	24.65	25.08	24.80	24.73	24.3
Minimum (cm)	24.21	23.95	24.29	24.23	24.31	24.22
Mean (cm)	24.84	24.25	24.75	24.40	24.67	24.45
Percentage of shrink (%)	2.20	4.53	2.56	3.94	2.87	3.74



a) Warp direction



b) Weft direction

Figure 3.1: Shrinkage test

Based on the graph in Figure 4.1, laundering caused the fabric to have a loss in fabric shrinkage. For the warp direction, for powder shows that detergent with an amount of 33 grams treatment has the highest value of mean length followed with 66 and 80 grams which 24.83 cm, 24.88 cm, and 24.80 cm, respectively. While liquid showed the biggest loss compared to powder. The amount of 33 grams detergent showed the highest mean followed by 66 and 80 grams which the value is 24.84 cm, 24.75 cm, and 24.67 cm respectively.

For the weft direction, liquid still showed the lowest value compared to powder treatment. Liquid treatment shows that detergent with an amount of 80 grams treatment has the highest value of mean length followed with 66 and 33 grams which 24.45 N, 24.40 cm, and 24.25 cm respectively. While powder detergent shows 80 grams have the highest mean followed with 66 and 33 grams which the value of the length is 24.75 cm, 24.67 cm, and 24.29 cm respectively.

In a nutshell, it can be seen both detergents show a loss in length and width after laundering. Yet, the loss is not critical. As can be seen in the figure above, the percentage for both directions is between 2 and 5 percent. The type of shrinkage that occurred for this fabric is relaxation shrinkage. Cotton is a natural fibre, which gives it its softness, but it is still more prone to shrinking than synthetic fabrics like polyester (Jayawardana et al., 2016). The fibres are spread as raw cotton is spun into yarn. It creating the tension required to weave the fibres into cotton cloth. The explanation for this is that cotton cloth shrinks when it comes into contact with water (Jain et al., 2019). Cotton fibres absorb water and shrink when exposed to it. It can be seen that the increased amount of detergent can affect the shrinkage loss that occur in the fabric. It is because of the reaction of fabric towards the volume of detergent which affects the construction of yarns and fabrics (Nasir et al., 2013). Laundering will break down the molecular structure for fabric (Balpetek et al., 2018). Thus, it affects the fabric dimension after treatment.

3.2 Tensile Test

The final results were plotted into graphs to compare the differences in each treatment. These were taken from the average break load of the three specimens cut along the warp and weft direction respectively for each sample. Table 3.2 shows the summarized result for this test.

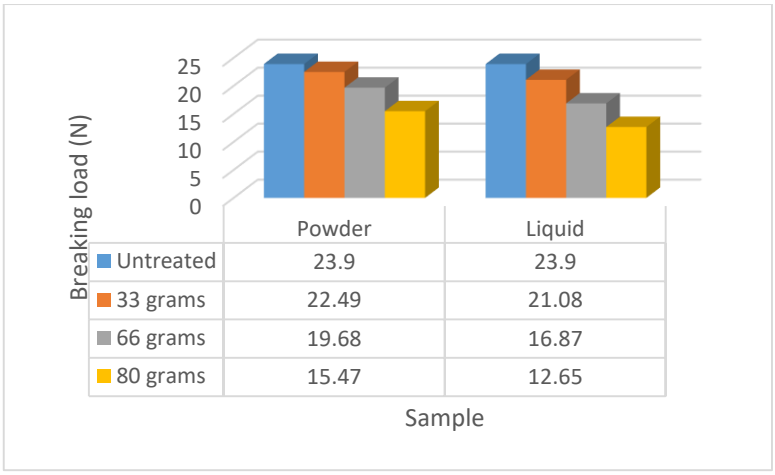
Table 3.2: The summarized result of tensile strength test

a) Powder detergent

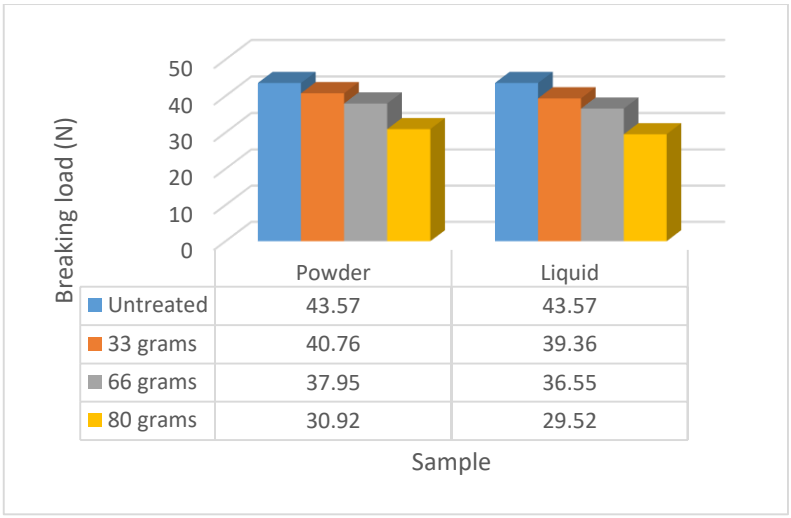
Break load	Untreated		33 grams		66 grams		80 grams	
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Maximum (N)	29.52	50.60	29.52	46.39	21.08	42.17	16.87	42.17
Minimum (N)	16.87	37.95	16.87	33.73	16.87	33.73	12.66	21.08
Mean (N)	23.90	43.57	22.49	40.76	19.68	37.95	15.47	30.92
Percentage of loss (%)			5.90	6.45	17.66	12.90	35.27	29.03

b) Liquid detergent

Break load	Untreated		33 grams		66 grams		80 grams	
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Maximum (N)	29.52	50.60	25.30	42.17	21.08	42.17	16.87	33.73
Minimum (N)	16.87	37.95	16.87	29.52	12.65	29.52	8.43	25.30
Mean (N)	23.90	43.57	21.08	39.36	16.87	36.55	12.65	29.52
Percentage of loss (%)			11.80	9.66	29.41	16.11	47.07	32.25



a) Warp direction



b) Weft direction

Figure 3.2: Tensile strength test

According to the graph in Figure 4.22, detergent treatment onto fabric caused the fabric to have the greatest loss in tensile strength. For the warp direction, liquid illustrates the biggest loss compared to powder. The amount of 80 grams detergent showed the lowest mean followed by 66 and 33 grams which the value of the break load that are12.65 N, 16.87 N, and 21.08 N respectively. While for powder shows that detergent with an amount of 80 grams treatment has the lowest value of breaking load followed with 66 and 33 grams which 12.65 N, 16.87 N, and 21.06 N respectively.

For the weft direction, liquid still showed the lowest value compared to powder treatment. Powder detergent shows 33 grams have the highest mean followed by 66 and 80 grams which the value of the break load is 40.76 N, 37.95 N, and 30.92 N respectively. While for liquid shows that detergent with amount of 33 grams treatment has the highest value of breaking load followed by 66 and 80 grams which 39.36 N, 36.55 N, and 29.52 N respectively.

In general, the weft direction break load was higher than the warp direction. It is because the fabric count of the weft direction is greater than the warp direction. It makes fabrics with a high count have higher tensile strength (Ansari, 2017). Both detergents treatment also causing the fabric to lose its tensile strength. The decrease of tensile strength may be due to fibre strength losses. It is because fibre strength is correlated with fabric tensile properties with similar yarn structures. The result from the breaking strength test proved the theory that liquid has high breaking strength (Davis, 2004). The data analysis

of this experiment, identified that powder cleaning agents are more stable than liquid cleaning agents. When liquid detergent is combined with water, it loses its ability (Toshikj et al., 2016). This can be happening because liquid detergent has a different approach compared to powder. Liquid have tendency to make fabric changed in fabric structure which can be resulting in high tensile strength (Toshikj et al., 2016). Another trend that can be noticed is the higher the amount of detergent, the lowest tensile strength. It is because of the concentration in detergent that influence the fabric strength (Bajpai & Tyagi, 2007). The detergent itself can gives drawback on fabric. When the amount of detergent is higher so it can cause more yarn construction swell closely.

3.3 Tearing Test

The final results were plotted into graphs to compare the differences in each treatment. These were taken from the average peaks load of the three specimens cut along the warp and weft direction respectively for each sample. Table 4.3 shows the summarized result for this test.

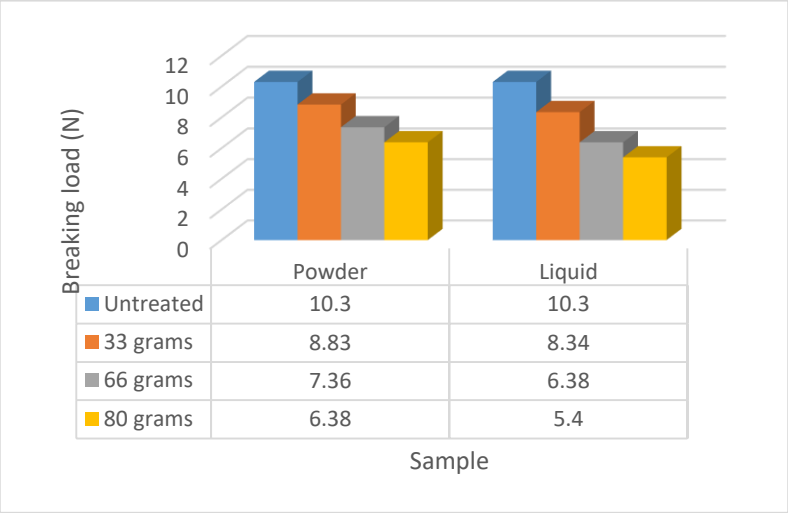
Table 3.1: The summarized result of tearing strength test

a) Powder detergent

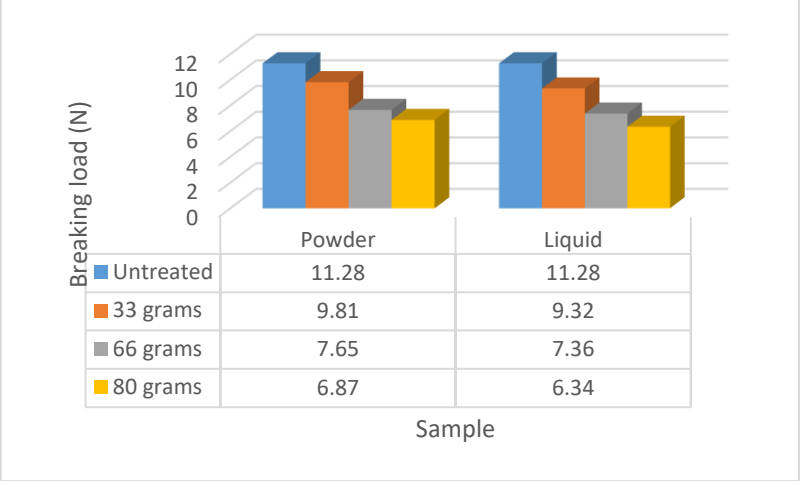
Break load	Untreated		33 grams		66 grams		80 grams	
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Maximum (N)	13.24	11.77	10.30	11.77	10.30	8.83	7.36	7.36
Minimum (N)	8.83	10.30	.7.36	7.36	4.14	5.89	5.89	4.14
Mean (N)	10.30	11.28	8.83	9.81	7.36	7.85	6.38	6.87
Percentage of loss (%)			8.69	13.03	28.54	30.41	38.45	39.10

b) Liquid detergent

Break load	Untreated		33 grams		66 grams		80 grams	
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Maximum (N)	13.24	11.77	10.30	11.77	7.36	8.83	7.36	7.36
Minimum (N)	8.83	10.30	5.89	7.36	5.89	5.89	4.14	4.14
Mean (N)	10.30	11.28	8.34	9.32	6.38	7.36	5.40	6.34
Percentage of loss (%)			19.03	17.38	38.06	34.75	47.57	43.79



a) Warp direction



b) Weft direction

Figure 3.3: Tearing strength test

According to the graph in Figure 4.37, there is an increase of value for the tearing strength of cotton fabrics for each detergent used. For the warp direction, powder illustrates the smallest loss compared to liquid. The amount of 33 grams detergent showed the highest mean followed with 66 and 80 grams which the value of the break load that are 8.83 N, 7.36 N, and 6.38 N respectively. While for liquid shows that detergent with amount of 33 grams treatment has the highest value of breaking load followed by 66 and 80 grams which 8.34 N, 6.38 N, and 5.40 N respectively.

For the weft direction, the powder still showed the highest value compared to liquid treatment. Liquid treatment shows that detergent with amount of 80 grams treatment has the lowest value of mean strength followed by 66 and 33 grams which 6.87 N, 7.65 N, and 9.81 N respectively. While liquid detergent also shows 80 grams have the lowest mean followed with 66 and 33 grams which the value of the break load is 6.34 N, 7.36 N, and 9.32 N respectively.

In conclusion, detergent treatment can increase the tearing strength of cotton fabrics. Fabric shrinkage could explain the small increase in tearing strength between cotton fabrics without detergent and cotton fabrics treated with detergent. When cloth shrinks, the warp and weft yarns become more coherent and closer together. It caused increasing tearing strength (Eryuruk & Kalaoğlu, 2015). The laundering causes the loosely warp and weft yarns. In addition, fabric count and yarn count affect tearing load differences. Fabrics with a low count and less interlacing having a higher tearing strength (Ansari, 2017). Results from this test proved the theory that plain weaves have high breaking strength, but lower tearing strength (Eryuruk & Kalaoğlu, 2015). The tearing strengths are much lower than breaking strengths because there is only one or a few yarns are broken at a time in tearing strength. While the breaking strengths of fabric is due to the breaking of many yarns at a time and therefore, is usually higher than tearing strengths (Eryuruk & Kalaoğlu, 2015). Another pattern that can be seen is that the more detergent used, the lower the tearing strength. The fabric strength is influenced by the intensity of detergent (Bajpai & Tyagi, 2007). The water consistency, the form of detergent used, and the drying conditions all play a role in the degree of damage (Hashimoto et al., 2018). For this study, since the amount of water, ballast load and drying condition are constant parameter. The only parameter that have variation is detergent. As a result, it has an effect on the strength of fabric during treatment (Bajpai & Tyagi, 2007).

4. Conclusion

The experimental study can be concluded that the objective of this thesis has been achieved where the influence of laundry detergent on shrink, tensile, and tearing test on cotton fabric had been determined. Comparing the strength among the amount of detergent, it was found that increasing the volume of detergent used affects fabric strength. The reason for this is that the detergent concentration acts on the cloth, affecting the construction of the fabric. It can also be shown that powder is more stable than liquid. It is because liquid detergent takes a different approach than powder detergent. Liquid have tendency to make fabric changed in fabric structure which can be resulting in high tensile strength. The shrinkage test found that the shrinkage occurred in both directions. It is triggered as tension is applied to yarns and fabrics during the manufacturing process. The percentage of loss is between 2 until 5 percent. The tension is released once the fabric is cleaned or steam pressed. It causes the fabric to shrink to its natural size. The result for the tensile strength test showed that fabric with both detergent treatments would have an obvious breaking strength. It is because the loss of tensile strength may be due to the losses of fibre strength where for similar yarn structures. Fibre strength is correlated with yarn tensile properties. The percentage of loss for this test is between 5 to 48 percent. Lastly, it was noted that tearing strengths were much lower than the tensile strength test. It is because there are only one or a few yarns broken at a time in tearing strength. While the breaking strength of fabric is due to the breaking of many yarns at a time, so it resulting in a higher than tearing strength test. The percentage of loss for this test is between 8 to 44 percent.

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References

Ansari, I. Z. (2017). Changes in Mechanical Properties of Denim Due to Different Washing Processes. *International Research Journal of Engineering and Technology*, *4*(10), 1424–1427.

Azam, M. S., Saleh, M. abu, & Nafiz, K. A. (2009). *An introductory knowledge about garments manufacturing technology*. Dhaka: Books Fair Publication.

Bajpai, D., & Tyagi, V. K. (2007). Laundry detergents: an overview. *Journal of oleo science*, *56*(7), 327–340.

Balpetek, F. G., Bozaci, E., Karakaya, P. S., Özdoğan, E., Demir, A., & Gülümser, T. (2018). Multi-cycle washing of cotton and the results in manner of DP. *Textile and Apparel*, *28*(4), 311–318.

Davis, J. R. (2004). Introduction to Tensile Testing. *Tensile Testing* (2nd ed., pp. 1–13). Almere: ASM International.

Eryuruk, S. H., & Kalaoğlu, F. (2015). The effect of weave construction on tear strength of woven fabrics. *Autex Research Journal*, *15*(3), 207–214.

Hashimoto, Y., Kim, K. O., Hashimoto, K., & Takatera, M. (2018). Effect of washing and drying conditions on dimensional change in various articles of knitted clothing. *Journal of Fiber Bioengineering and Informatics*, *11*(4), 227–240.

Ibrahim, H. M. M., & Hassan, M. S. (2016). Characterization and antimicrobial properties of cotton fabric loaded with green synthesized silver nanoparticles. *Carbohydrate Polymers*, *151*, 841–850. Elsevier Ltd.

Jain, A. K., Tesema, A. F., & Haile, A. (2019). Development of shrink resistance cotton using fluorocarbon. *Fashion and Textiles*, *6*(1), 1–10. Springer Singapore.

Jayawardana, T. S. S., Fernando, E. A. S. K., Wijesena, G. H. D., & Kuruppu, R. (2016). Development an Effective Quick Fabric Relaxation Machine. *International Journal of Engineering Trends and Technology*, *42*(6), 310–318.

Kovar, R. (2010). Anisotropy in woven fabric stress and elongation at break. *Woven fabric engineering*, 1–24.

Leverette, M. M. (2019). What Causes Clothes to Shrink in the Laundry. *The Spruce*. Retrieved November 10, 2020, from https://www.thespruce.com/why-clothes-shrink-in-the-laundry-2146152

Majumdar, A., Shukla, S., Singh, A. A., & Arora, S. (2020). Circular fashion: Properties of fabrics made from mechanically recycled poly-ethylene terephthalate (PET) bottles. *Resources, Conservation and Recycling*, *161*, 1–10. Elsevier.

Nasir, E., Dias, T., Tulos, N., Musa, A., Baharudin, A., & Ruznan, W. S. (2013). Dimensional Stability of Cotton / Acrylic Plain Knitted Structure Produced With Flat-Bed Knitting. *Journal of Academia*, *3*, 20–33.

Schlag, M. T., & Ordonez, M. (2010). Comparison of the effects of a top-loading and a front-loading washing machine on cotton fabric. *In: Proceedings of the annual international conference & exhibition of AATCC*.

Toshikj, E., Jordanov, I., Demboski, G., & Mangovska, B. (2016). Influence of multiple laundering on cotton shirts properties. *Textiles and Configuration*, *26*(4), 393–399.

Toshikj, E., & Mangovska, B. (2011). Effect of Laundering of Cotton Knitted Fabrics with Different Stability and Colour Fastness. *Industry of Textile*, *2*, 5–11.

Yuan, J., Sun, F., & Ding, X. (2013). Mechanism and influencing factors of woven fabric wrinkling during domestic tumble laundering. *China Appliance Technology*.

Zambrano, M. C., Pawlak, J. J., Daystar, J., Ankeny, M., & Venditti, R. A. (2020). *Impact of dyes and finishes on the microfibers released on the laundering of cotton knitted fabrics*. *Environmental Pollution*. Elsevier Ltd.