Material characterization of a plain weave cotton fabric using a plain stich by stich density

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ABSTRACT

This study aims to increase the extent of information available for reference in the design of fabric structures, characterizing a widely used fabric in the Do It Yourself (DIY) industry for several projects, with the focus of designing the product to manufacture as an engineering structure taking into consideration load paths and load directions.

Testing for the factors of seam strength with a plain stitch, varying seam density and fabric orientation, with data obtained through testing using the ASTM 1683 standard (ASTM international, 2016), data on seam strength and displacement before failure of the different test subjects will be given and compared to provide the reader with a better understanding of the material.

INTRODUCTION

Due to the anisotropic and nonlinear behavior of fabric, materials and products fabricated from them are hard to properly design and predict, generally a great deal of trial and error is involved in their development. One of the factors that contributes greatly to the overall durability and functionality of this products is seam strength (Barbulov, Cirkovic, & Stepanović, 2012); this parameter is highly dependent on all the components of the seam.

The parameters that predict seam strength are fabric type, orientation, weight, strength and durability; thread material, fiber type, construction and caliber; stich type, seam construction and stich density (American & Efrid). All of these contribute to the unpredictable nature of this element in the construction of fabric products; therefore, is required to do either preliminary testing of the materials and methods to use, and subsequent tests of the finalized product.

Current methods to predict seam strength

Currently, most of the effort to predict seam strength and failure characteristics are defined through computational methods and data analysis (Sarkar, Al Faruque, & Mondal, 2021); most of these methods, present a linear correlation between stitch density, fabric strength and tread strength, but due to the multiple factors that act on this joint- most of this methods can't fully predict the nonlinear behavior of said joint and only work in specific cases (Sarkar, Al Faruque, & Mondal, 2021). Some of them are the orientation of the seam in the fabric (Öztaş & Gürarda, 2019), the type of stich performed, the stich density, type of fabric used.

As a consequence of the different prediction methods being highly specific, is difficult to find general guidelines or information; especially, when the application requires some degree of accuracy, the best option is to either search the literature for information on the specific use case scenario or execute testing with the combination of methods and materials required for the application.

The knowledge of the tensile strength in a seam is frequently required in applications were the fabric will be under stress or where durability is required such as in parachute production (Dhanaswamy, Kirubakar, & Manuswamy, 2017), under certain circumstances seams should be avoided due to the deterrent effect they have on the general strength of the product.

Goals

With this study the goal is to characterize a piece of commonly available fabric widely used in homemade projects that require durability and strength with certain rugged aesthetic (such as tool bags, or tool rolls). This being plain weave canvas, with a basic type of stich (Callister, 2015) widely available in even the simplest machines on the market, the plain stich.

MATERIALS AND METHODS

Sample preparation

This study was done using the testing protocol and methods described on the ASTM D1683 (ASTM international, 2016) with a plain weave canvas fabric of 167 g/ m^2, measured from a 10cm x 10cm square sample (Figure 1); from this, the thread and seam parameters were defined in accordance with what the standard required: 25mm of seam allowance using a cotton *Tex 70* thread with a *medium ball #43 needle*.

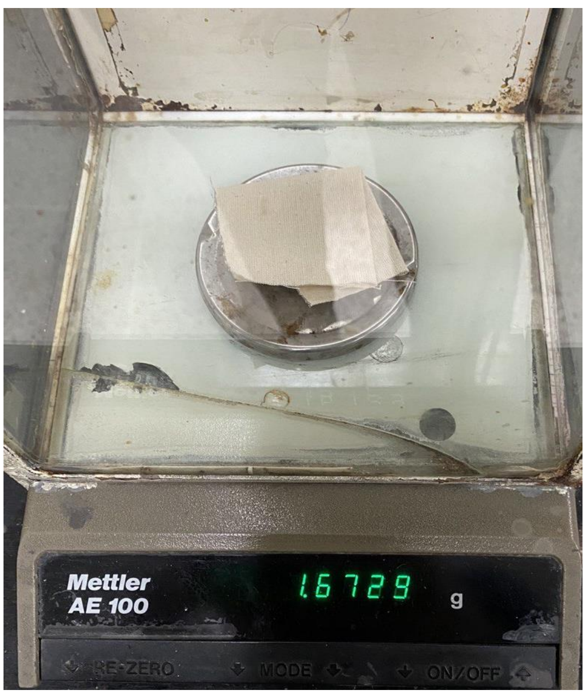

Figure 1. Fabric density measurement

The test specimens were cut using a laser cutter (Figure 2).

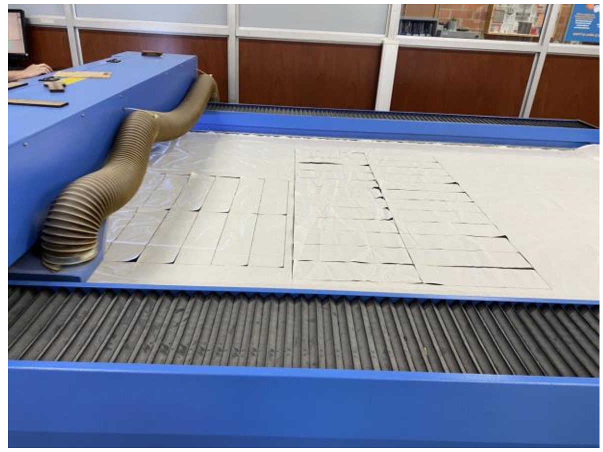

Figure 2. Sample cutting using laser cutter

After the cut specimens were sawn by an experienced operator in an industrial sewing machine, the stich densities decided on were 6.5, 7.5, 9, 10, 11, 12, 14, 16 & 18 stiches per inch with 5 samples per stich density, this were decided based on the standard base given of 12 stiches per inch.

Structure of the model

For this study, only two factors were considered: stitch density and fabric direction. These two factors are the easiest to control, for a beginner, when designing a fabric structure and provide a good amount of information without creating an overwhelming amount of test subjects.

Experimental methods.

The machine used for the test was an *Instron tension testing machine* with capacity for 10kN; with a traverse speed of 300mm per minute. All into accordance with ASTM D1683 (ASTM international, 2016)

Placed on 25mm wide jaws and using rubber pads as a buffer to avoid fabric damage due to the grab strength (Figure 3), after the setup was done the test was started until the machine identified rupture (Figure 4).

Figure 3. Setup of test specimen

Figure 4. Failure of test specimen

RESULTS AND DISCUSSION

The results presented were obtained compiling the data procured though testing for each of the stich densities and directions of fabric, taking the five-test average max strength (Table 1 and Table 2).

The average of both, seam strength and slippage, were graphed for comparison in between different stich densities and the base strength of the fabric (for weft comparisons see Figures 5 and 6; for warp comparisons see Figures 7 and 8).

Lastly, two graphs to compare results in between fabrics directions for both seam strength and displacement were created (Figures 9 and 10).

Stiches per inch	Fabric Direction	Weft	Warp
		Fabric Average Strength (N)	
Base Fabric		269	300
6,5		244	278
7,5		257	292
9		271	310
10		263	326
11		275	329
12		263	333
14		267	333
16		250	342
18		246	334

Table 1. Average Strength

stiches per inch	Fabric Direction	Weft	Warp
		Fabric Average Displacement (mm)	
Base Fabric		12,86	13,95
6,5		20,27	25,29
7,5		20,97	25,64
9		20,75	26,54

10	19,36	23,91
11	19,09	23,73
12	20,67	21,82
14	19,7	23,68
16	16,74	23,66
18	16,64	22,96

Table 2. Average Displacement

Weft Results

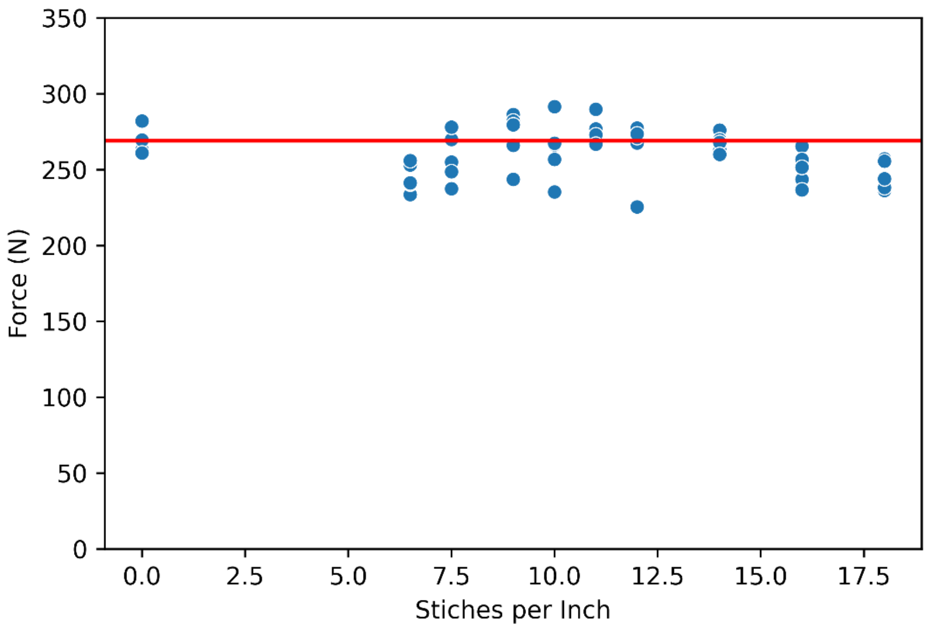

Figure 5. Weft seam strength

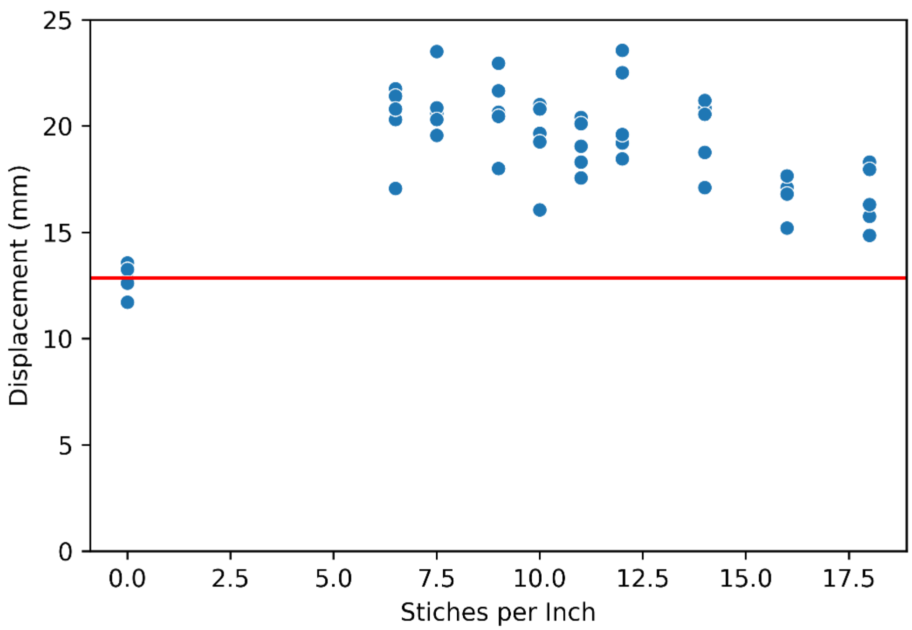

Figure 6. Weft seam Displacement

Warp results

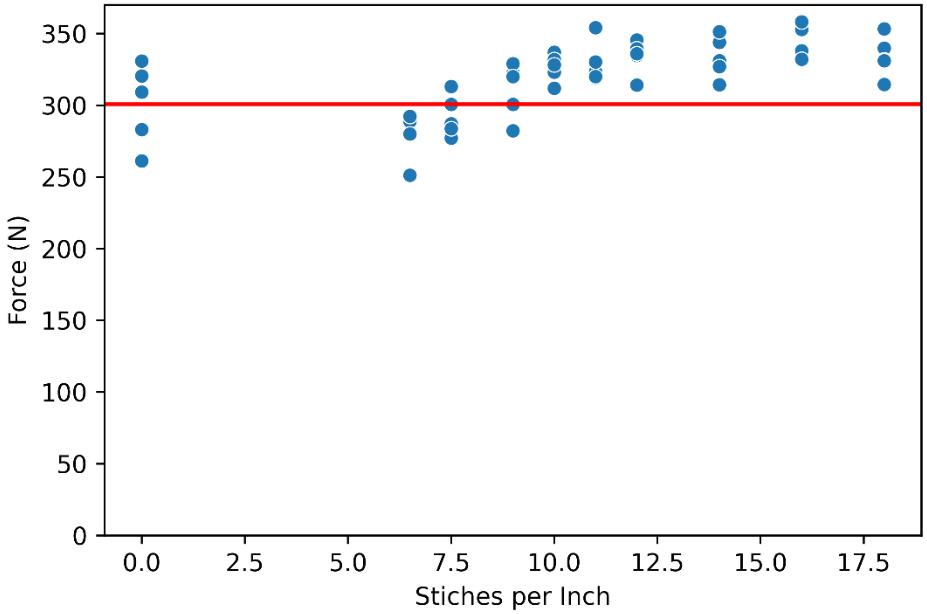

Figure 7. Warp seam strength

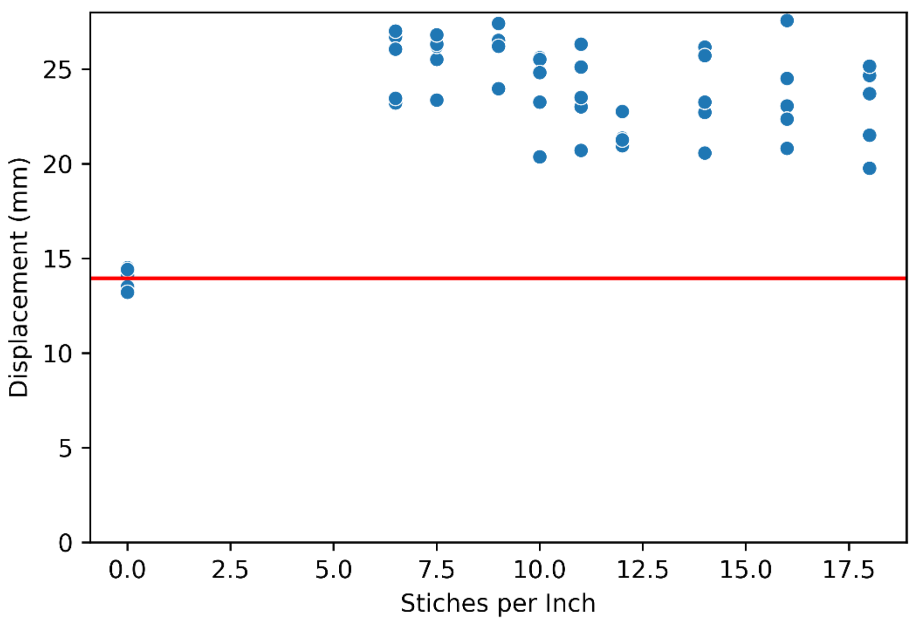

Figure 8. Warp seam Displacement

Fabric Direction Comparison

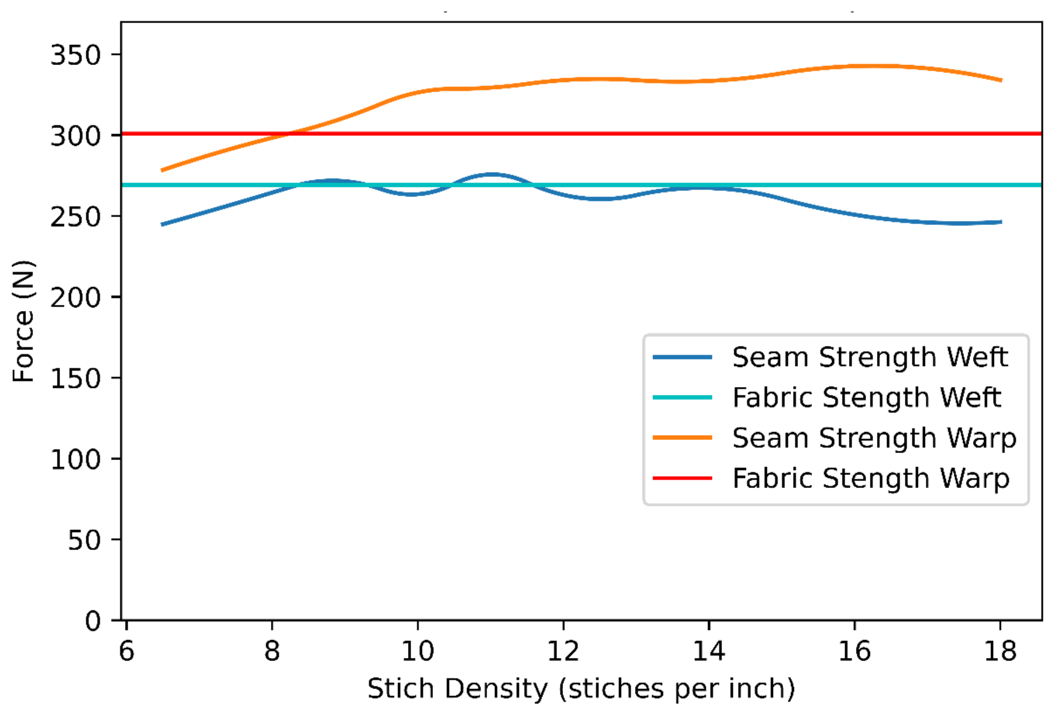

Figure 9. Seam Strength Comparison

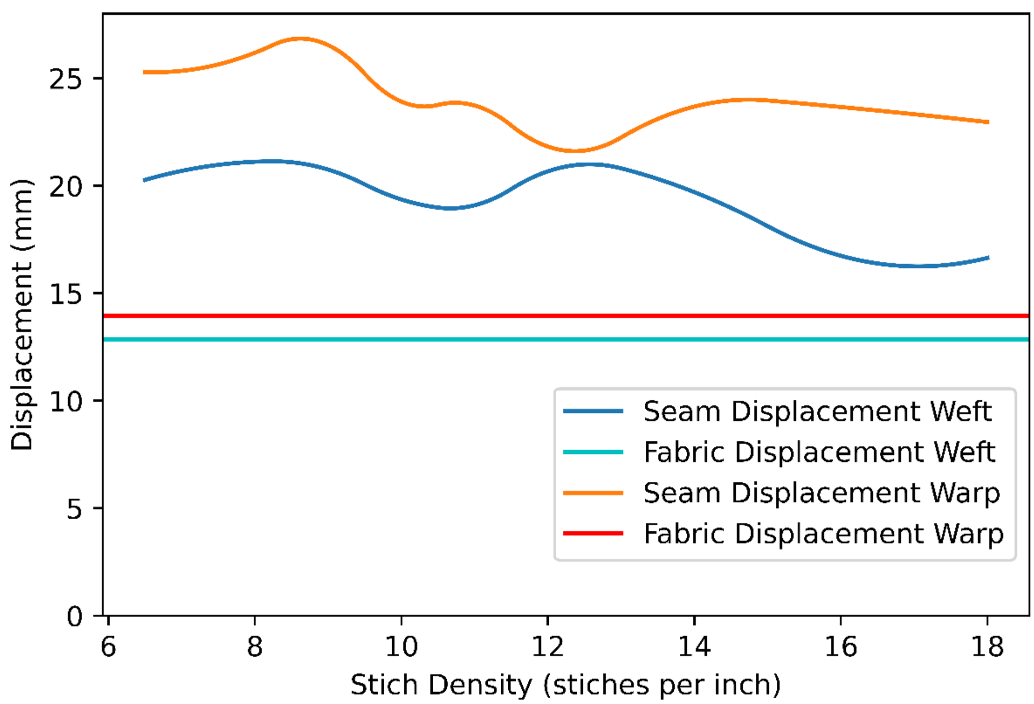

Figure 10. Seam Displacement Comparison

Result analysis

For this data set a confidence interval of 95 percent was assumed.

In figures 5 to 8 the high variability of the data in between tests is shown in the dispersion of the points with the red line representing the average of the control samples of fabric in the 0 stiches per inch mark.

In (Figure 5) a clear trend can be seen were the weft seam reaches maximum strength in between 9 to 11 stiches per inch, after this the performance of the seam decreases, this would indicate that after this point the damage done to the fibers of the base material is sufficiently significant to negate the benefit that more stiches in the seam would provide.

This does not translate to the displacement results (Figure 6) were after 12.5 stiches per inch an increase on stiffness to the joint can be noticed, this indicates that the additional threads in the joint are beneficial for the overall stiffness of it.

For the warp strength results (Figure 7) no clear increase on breaking force can be seen after 11 stiches per inch, and a decrease in strength after that point is not noticed, which would indicate that the damage done to the fabric is not significant enough, as to decrease the overall breaking strength of the joint.

In the displacement results (Figure 8) the data doesn't show any significant increase on stiffness of the joint at any point, a trend can be seen were the average stiffness increases with stich density, but the variability of the data doesn't allow to get a definitive answer.

Due to the anisotropic nature of fabric, it can be noticed that with the same stich density the strength of the fabric is greater in the warp direction comparing the reference values for fabric strength, this disparity increases with the increase in stich density in the samples tested, represented by the divergence of the lines in higher values of stich density. (Figure 9).

This anisotropy can also be noticed in the displacement chart (Figure 10). where the difference between the two directions of the fabric initial samples gets amplified once a seam is added, as can be noticed by comparing the base value represented by the fabric displacement reference values, and the seam displacement lines.

After analyzing all the strength versus displacement Figures, a clear tendency towards a fragile failure (Callister, 2015) can be noticed, this is represented by a decrease in displacement in the seam before failure, this in case would indicate that the failure mode is predominantly because of fabric rupture and not seam slippage. This can be also noticed in the samples after the test, all of them presented rupture in the seam line (Figure 3).

SUMMARY

- The warp direction offers increased strength and rigidity compared to the weft direction.
- The weft direction is weaker but provides more rigidity.
- If strength is the main factor on a seam the warp direction should be favored over the weft direction.
- If rigidity is important a bias towards using the weft direction of the fabric should be considered.
- Displacement in a seam before failure decreases with the increase of seam density.

CONCLUSIONS

From the analysis of the information obtained above, some conclusions which are oriented to the use of the subject material will be presented below.

- When using this fabric or similar alternatives, stitch density and fabric orientation, in each of the seams should be carefully chosen to extract the best possible performance out of the material; especially, in high-stress areas and load conducting structures.
- It is recommended to use the warp direction in high load areas where other kinds of reinforcement won't be present, due to the higher ultimate strength of the material in this direction but are inadvisable to use this direction in conjunction with parallel reinforcements. The difference in rigidity between these two areas might lead to tears or unwanted consequences.
- It is advantageous to use weft direction where high rigidity is required, as this deforms less under load even if the final strength of the joints and fabric is not the highest. Ideally, if one is reinforcing with other kinds of fabrics of bias tape, this direction would be also recommended as the difference in rigidity between the reinforced section and the rest of the panel would be less.
- In the topic of seam density, it changes from warp to weft with warp fabric presenting the best results around 17 stitches per inch, and the weft direction presenting the best performance lower in the range at 11 stitches per inch.
- If the fabric structure is designed with the appropriate safety factor in mind, the preferred option for high stiffness, and load transfer capability, would be using the weft direction of the fabric avoiding seams were possible. If seams are necessary, a high stitch density of around 17 stitches per inch would be preferred.
- For the opposite cases where high strength and toughness are the utmost priority, the warp direction should be preferred, with seams in the range of 17 stitches per inch.
- Due to the variability of the data when designing for a specified load, appropriate design factors should be used to allow for the inconsistency of the material strength.

CONTENTS

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