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# Effect of material and stitching on tensile properties of woven fabrics

**Z Ahmad[1,2], B K Sirkova[1,2], S Ahmad[1], M S Naeem[1] and S Z Hassan[3]**
[1] National Textile University, Faculty of Textile Engineering, Faisalabad, Pakistan.
[2] Technical University of Liberec, Faculty of Textile Engineering, Liberec, Czech Republic.
[3] Balochistan University of Information Technology, Engineering and Management Sciences, Faculty of Engineering, Quetta, Pakistan.
E-mail: zuhaibahmad.ntu@gmail.com

**Abstract:** The strongest growth potential for high strength fabrics and advanced composites is in high-performance applications such as aerospace, maritime, automotive and construction industries. The optimization of mechanical properties of these materials is very important in this regard. Therefore, this study has been performed where we have analyzed the effect of material and stitching on tensile properties of woven structures. For this purpose, double layer woven fabric structures have been prepared on sample weaving loom using Basalt and Glass yarns. Their tensile testing has been performed to analyze the impact of fabric parameters of tensile load. ANOVA (analysis of variance) results showed that stitch distance has insignificant impact on the strength of fabric while the effect of material and stitching on peak load was statistical significance.
**Keywords:** Woven structure, material, tensile load, stitching, binding points.

## 1. Introduction

Recent years have seen a considerable spread in polymer composite structural materials, which allows the development of alternatives that fulfill technical requirements and methods for improving their mechanical performance [1]. Carbon fibers and glass fibers are mostly used for composites making in conditions of high loads [2]. Basalt fibers are more commonly used because of additional benefits like reduction of cost, improved chemical and physical characteristics [3] and for the reinforcements of thermosetting polymers as compared to the conventional Glass or carbon fibers [4] [5] [6]. Basalt is a natural product from volcanic rock. Basalt rock is melted into fibres in a way that fibres with the diameter of 7–13 µm are formed from the melt at a temperature above 1500 ºC by the means of a centrifugal blowing process [2].

Most of the investigators worked on composites and single-layer woven fabrics, like Liu et al prepared polymer composites reinforced by basalt fabric and glass fabrics and concluded that there is no significant difference in their compression strength, shear strength, flexure strength and tensile strength [7]. Whereas, Lopresto et al investigated the Basalt and E-Glass reinforced plastic laminates were compared showing a high performance of the Basalt material in terms of mechanical properties [8]. Babu and Chairman evaluated Glass and Basalt fabric reinforced composites for analyzing their abrasive wear performance and mechanical properties [9]. Similarly, the significance of strain-rate effect on material properties of unidirectional Glass, Basalt, Carbon and plain-woven Aramid fabrics have been investigated by Yao and Zhu [10].

It is necessary to understand and evaluate the mechanical properties of woven structure before being used in composites. So, in this research work, the possibility of Basalt material as reinforcement material has been compared with E-Glass. The comparison has been done on the basis of impact of

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material, stich distance and the effect of stitching (between layers) has been determined on tensile strength and toughness of fabric.

## 2. Material and methodology

The continuous multifilament yarns of Glass 68*2 tex and Basalt 66*2 tex were used as raw material. The Basalt and Glass structures were produced on the sample weaving loom. The yarn count for warp and weft was kept the same while woven samples were produced in accordance with experimental design as can be seen from Table 1 [11]. The basic structures for stitched and unstitched fabrics have been shown in Figure 1. The conditioning of yarns before testing and fabric production have been achieved for one day. The Vibrodyn-400 instrument was used to measure the fineness and tenacity of Basalt and Glass fibers, in accordance with EN ISO 1973:1995.

**Table 1.** Experimental plan for construction of Basalt and Glass fabrics

| Sample Code | Ends/ cm | Picks /cm | Design | Sample Code | Ends/ cm | Picks/ cm | Design |
|---|---|---|---|---|---|---|---|
| **B1** | 16.2 | 18.2 | S.D.= 0.5 x 0.5 | **G1** | 16.2 | 18 | S.D.= 0.5 x 0.5 |
| **B2** | 16.2 | 18.2 | S.D.= 1x1 | **G2** | 16.2 | 18.2 | S.D.= 1x1 |
| **B3** | 16.2 | 18.2 | S.D.= 1x1.5 | **G3** | 16.2 | 18.2 | S.D.= 1x1.5 |
| **B4** | 16.2 | 18 | S.D.= 1x2 | **G4** | 16.2 | 18 | S.D.= 1x2 |
| **B5** | 16.2 | 17 | unstitched | **G5** | 16.2 | 17 | unstitched |

*B = Basalt fabric, G = Glass fabric, S.D. = stitching distance (cm)

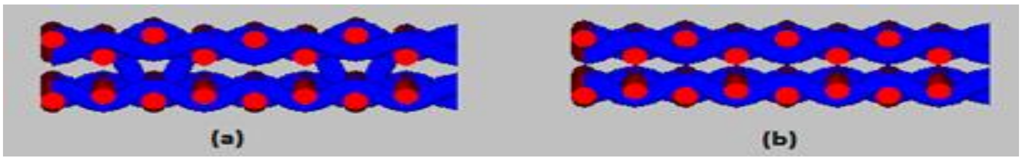


**Figure 1.** Two-layer fabric (a) stitched, (b) unstitched.

Similarly, TIRA 2300 instrument was used to measure the tensile properties of Basalt and Glass yarns accordance to ASTM D885. The average load-elongation curve for each yarn type was obtained by using Matlab software. Whereas the image analysis has been performed in accordance with IS 22-103-01/01 was used to determine the yarn diameter [12]. The twist tester of MesdanLab was used to measure the yarn twist for both materials in accordance to ASTM D1422. Fiber specification and characteristics of yarns for Glass and Basalt can be seen from Table 2.

The Testometric M350-10CT machine as shown in Figure 2 has been used to measure the tensile properties of all woven fabrics following EN ISO 13934-1. The load-elongation curve data for each of woven fabric (five samples) were obtained. Later the average curve for each type of fabric sample was obtained using Matlab software. The statistical significance was calculated by using ANOVA (at $\alpha$= 0.05) for tensile strength of fabrics.

**Table 2:** Characteristics of Basalt and Glass fibers and yarns

| Parameters | Basalt fiber | Glass fiber | Parameters | Basalt Yarn | Glass Yarn |
|---|---|---|---|---|---|
| Fineness (dtex) | 1.72 | 1.56 | Fineness (tex) | 132 | 138 |
| Diameter (um) | 10 | 9 | Diameter (mm) | 0.44 | 0.42 |
| Tenacity (cN/tex) | 96.97 | 111.2 | Tenacity (cN/tex) | 46 | 40.18 |
| Breaking strain (%) | 3.66 | 4.23 | Breaking strain (%) | 2.96 | 2.7 |
| Density (g/cm$^3$) | 2.8 | 2.56 | Twist per meter | 94 | 148 |

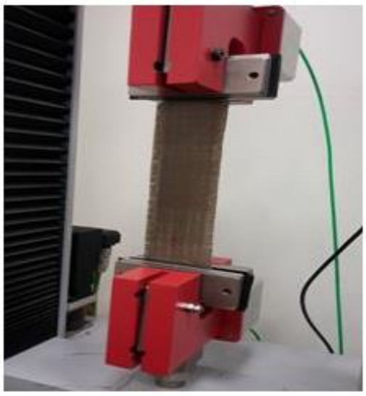

Figure 2. Tensile testing of sample fabrics

## 3. Results and Discussions

When a woven fabric is subjected to a tensile loading then it goes through the four regions in a load-elongation curve, which has been explained here in Figure 3. The viscoelastic nature of both materials can be observed here as a low slope can be observed in the starting phase which is the first region. Later, in the second region it rises steeply. In first region which is also called the crimp region, the crimp is decreased in one set of yarn during tensioning while it increases in other set of yarn, it is also called the crimp interchange. Hence a large increase in elongation at a low load level in the crimp region can be observed in the curve of load elongation. In the second region, when more extension is added in the fabric by the application of force, the extensions in fibers as well as in yarn also starts. The slope of curve in comparison to previous region increases when straightened yarns bear more load which is termed as elastic region. As far as the non-linear part of load elongation curve is concerned, it can be seen from the third region (which is non-linear part of failure region) before tensile strength is reached. It is because of random breakage of filaments present in bundles of yarn which is also prior to their localized failure. In the last stage which is the post peak region, a swift decrease in the load beyond the tensile strength can be observed, which links to the increasing yarn failure [13].

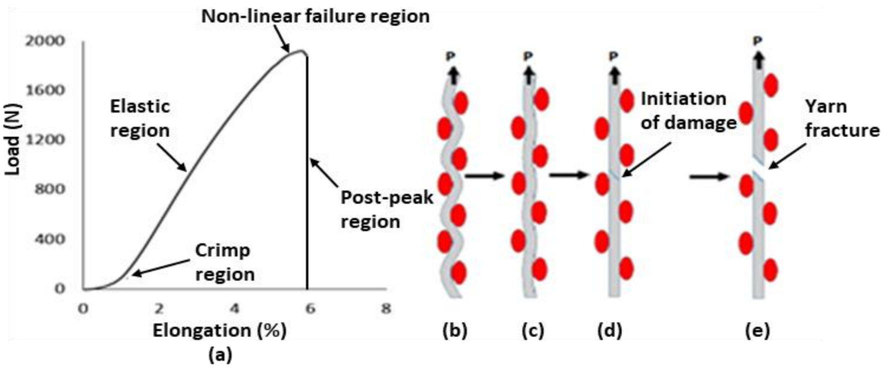


**Figure 3.** (a) Load-elongation curve during tensile loading, (b) crimp region, (c) elastic region, (d) non-linear failure region and (e) post-peak region (adapted and reproduced) [10]

Figure 4 shows the curve for load-elongation for two-layer Basalt woven fabrics in both (warp and weft) directions. The impact of stitch distance and stitching on curve of load elongation can also be seen from figure. The curves of load elongation for all stitched fabrics (B1-B4) are close to each other in both directions which clearly shows that stitch distance has no effect on tensile load. All two layer stitched fabrics bear similar load but a little high deformation (elongation %) in both directions, when we compare the all stitched fabrics (B1-B4) with the curve of unstitched fabric (B5). From these results it can be concluded that stitching points cause a little influence on elongation % but remain ineffective during breaking load. This is due to the fact as the stitching points connects the two-layer and the rate of stitch points increase the overall crimp in the yarns, which permits them to deform (extend) more before breakage along both directions. It is also not preferable to have more number of stitch points in a woven fabric as in case of (B1), the woven fabric sample exhibits the low tensile load values along both warp and weft direction. The stitched woven fabrics have been found less rigid as compared to unstitched woven fabric. In Table 3, the statistically significant of stitching between two layers of fabric can be observed which is found significant.

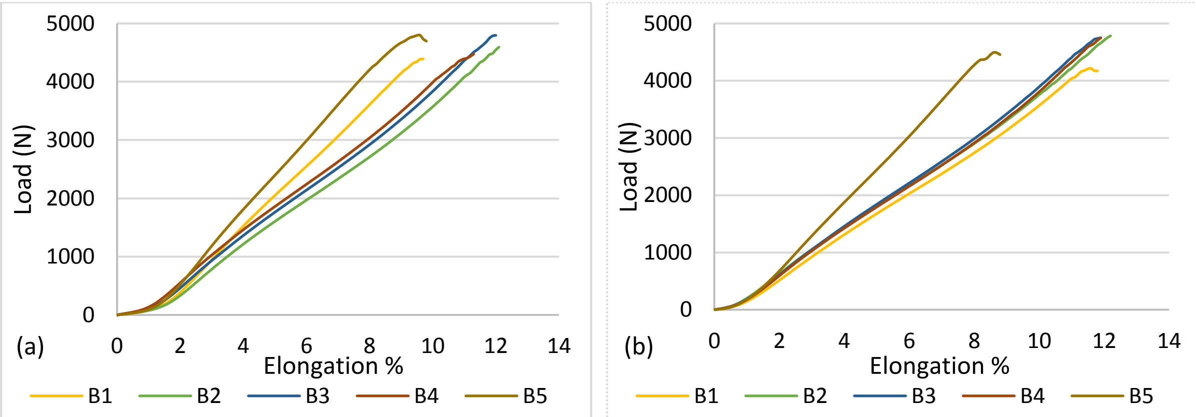


**Figure 4**. Average Load vs elongation curves for Basalt fabrics along (a) weft and (b) warp.

Similarly, the impact of stitching and stitch length between two layers of fabric can be analyzed in Glass woven fabric samples can be seen from figure 5. It can be analyzed that no sufficient difference exists in tensile strength when we compared two-layer stitched fabrics (G1-G4), stitch distance also has insignificant impact in both directions. Also, the unstitched fabric (G5) has similar tensile strength and less elongation % along both directions as compared to stitched fabrics (G1-G4).

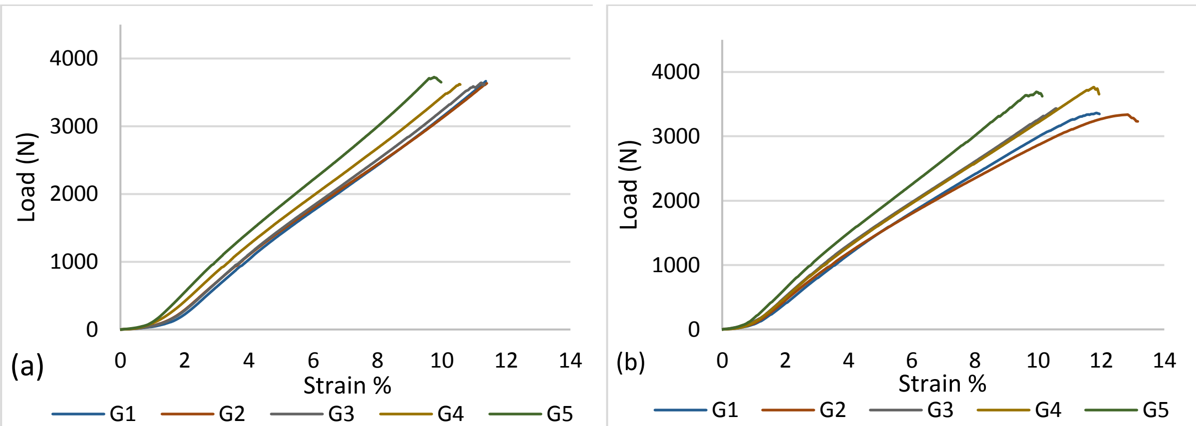


**Figure 5.** Average Load vs elongation curves for Glass fabrics along (a) weft and (b) warp.

WOR (work of rupture) is defined as the energy required to break a material or total work done to break that material. It is also a measure of toughness of material (area under the load-elongation curve) and been calculate for all fabric samples using equation 1. A small section of force extension curve is "*dl*" and within this small section the force "*F*" is constant as shown in

Figure **6**, while this force increases the sample in length by an amount *dl* [14].

The WOR of a material is proportional to its areal weight (GSM) for fabrics and to their original sample size (area). So, in order to compare the sample fabrics their specific work of rupture (SWOR) has been calculated using equation 2 and shown in Figure 7.

$$Work\ of\ rupture = \int_{0}^{break} F.dl \quad (1)$$

$$\text{Specific work of rupture} = \text{SWOR} = \frac{\text{Work of rupture}}{\text{Areal weight x Initial Area}} \quad (2)$$

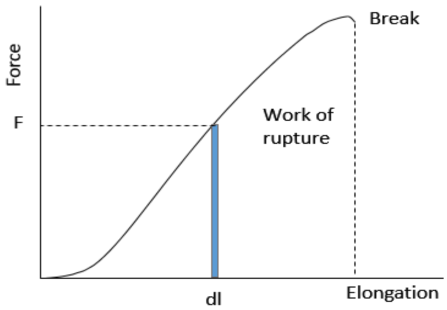


**Figure 6.** Work of rupture in force extension curve

It can be observed in Figure 7 that all Basalt fabrics exhibits higher toughness as compared to Glass fabrics along both directions. Basalt yarn exhibits higher tenacity than Glass yarns (table 2), similarly their load-elongation values are higher, consequently it leads to higher toughness in Basalt woven fabrics. When the unstitched fabric samples (B5) and (G5) having same density and cross-sectional area as stitched fabric samples (B1-B4) and (G1-G4), are compared with their respective material to analyze the impact of stitching on toughness of fabric then it can be observed that the addition of stitching points increases the toughness as it combines the two-layers and allow them to have high strain values before breakage along both directions of applied load. Whereas the impact of stitch distance is not so noticeable in stitched fabrics (B1-B4) and (G1-G4) along both directions.

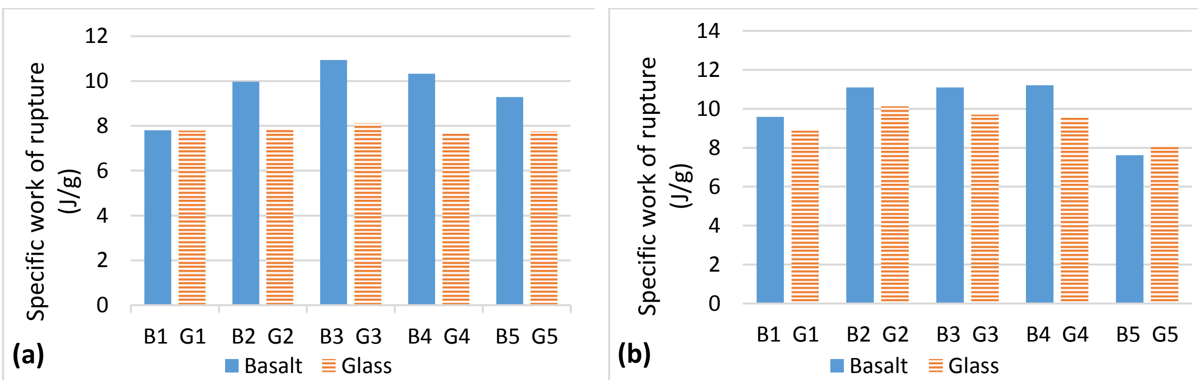


**Figure** 7. Specific work of rupture for Basalt and Glass woven fabrics along (a) weft and (b) warp

Figure 8 shows the effect of material which is very important for reinforcement materials and in case of Basalt as an alternate material to the Glass structures. The peak load values of woven structures of both materials can be compared along both directions. All the stitched and unstitched structures of Glass material exhibit low peak load values as compared to the Basalt woven structures along both warp and weft directions. As we can see in Table 2, the Basalt yarns have more tenacity as compared with Glass yarn and the similar behavior can be observed in both kind of fabrics as well. The variation of the load in all stitched fabrics has already been observed in load-elongation curve data and here in Figure 8 the peak load analysis also shows insignificant results for both Basalt and Glass structures. Moreover, in Table 3, the ANOVA results explains the statistical significance of material on peak load of fabric as P value is less than 0.05.

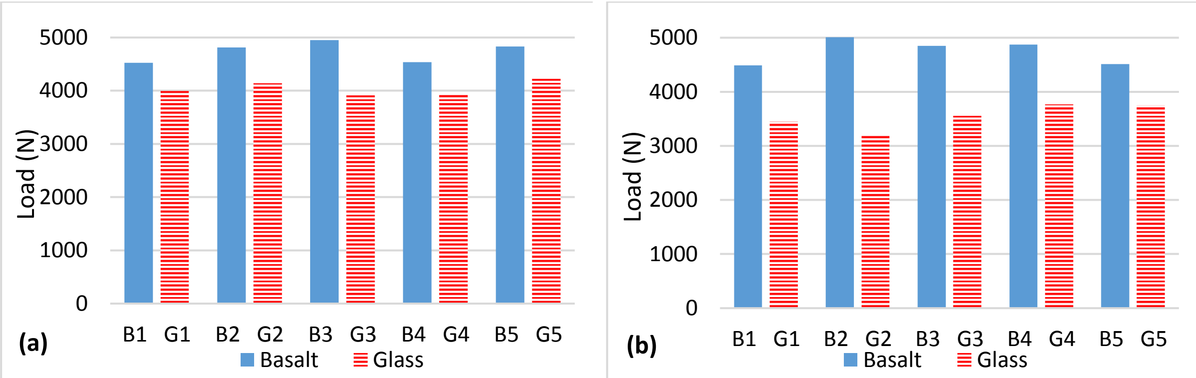


**Figure 8.** Peak load of Basalt and Glass woven fabric samples along (a) weft and (b) warp

The material effect applied load direction (warp, weft), stitching distance, stitching between two layers of fabric and their interactions on fabric strength can be observed in Table 3. It shows the statistically significant effect different parameters on peak load of woven fabric if the P value is less than 0.05.

**Table 3.** ANOVA results for peak load (N)

| Source | Two-layer stitched Fabrics Significance | Two-layer unstitched fabric Significance |
|---|---|---|
| Material | 0.000 | 0.000 |
| Direction (weft, warp) | 0.002 | 0.000 |
| Stitching distance | 0.091 | - |
| Stitched vs Unstitched | - | 0.020 |
| Material * Direction | 0.000 | 0.000 |
| Material * Stitching distance | 0.033 | - |
| Stitching distance * Direction | 0.066 | - |
| Material*stitched vs unstitched | - | 0.001 |

## 4. Conclusions
The following conclusions can be made from this study.

- The values of load-elongation curves for Basalt and Glass stitched woven fabrics are close to each other and the effect of stitch distance between two layers of fabric has been found statistically insignificant as well along warp and weft direction.

- The two-layer unstitched fabric (B5) and (G5) have also the same amount of peak load as compared to their relevant stitched structures (B1-B4) and (G1-G4), with slightly less amount of extension along warp and weft direction. It explains that the stitching or connection points between two layers of woven fabric affect little on extension percentage only and not on peak load.
- The toughness of Basalt fabrics is more as compared to Glass woven fabrics, similarly it is concluded that the effect of material on tensile strength of fabric is prominent along both direction of applied load.
- Two-way ANOVA results concluded that the effect of stitch distance between two layers of fabric is insignificant, whereas the material effect, applied load direction (warp, weft) and stitching between two layers of fabric is statistical significance.
- The Basalt material can be a good alternative to E-Glass as it has shown good material properties regarding tensile for stitched and unstitched two-layer woven fabrics.

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