Strength loss of glass yarn during weft knitting

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Strength loss of glass yarn during weft knitting

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Abstract
Weft-knitted fabrics from glass yarns present many advantages in technical textile applications. However, due to their stiff and brittle nature; glass fibers can easily be broken during weft knitting process that creates broken fiber ends on the fabric surface, and deteriorates the performance of resultant fabric. In this study, weft-knitted glass fabrics with four different knit architectures, and two different cam settings were produced. Number of yarn ply was also varied as 2- and 3-ply. The effect of all these input parameters on strength loss of glass yarn was examined via measuring virgin and unravelled yarn strengths in loop form. Results showed that knit pattern, cam setting and number of yarn ply did not affect the unravelled loop yarn strength at statistically significant level. On the other hand; unravelled yarns exhibited better loop strength than virgin yarns that was attributed to uniform distribution of fibers over cross sectional area of yarn as a result of knitting process.

Keywords: glass fiber, technical textiles, weft-knitted fabric, loop yarn strength

1. Introduction
Weft-knitted fabrics have stretchable, three dimensional, intermeshed, and porous structures that make them distinctive as compared with woven and nonwoven fabrics. Due to their snug fit comfortable nature, they are widely used in apparel production. They are also used in many technical textile applications. Once high performance fibers are converted into weft knitted fabrics, they offer unique advantages: comfortable protective clothing against flame or chemicals, reinforcements for impact resistant composites, and filter media for filtration of hazardous materials [1, 2]. Due to their low price, good mechanical properties, and high resistance against flame and chemicals; glass fibers are widely used in technical textiles applications. Stiff and brittle nature of glass fibers make their conversion into weft knitted fabrics challenging. Glass fibers can easily be broken, as they are forced to take loop shape, and broken fibers deteriorate the surface appearance and performance of knitted fabrics in the following service life. Quantification of this fiber breakage (damage) and determination of the most influential process and product input parameters on strength loss of the yarn after knitting process is crucial [3, 4]. Therefore, weft-knitted fabrics from glass yarn were produced within the context of this study. Knit pattern, number of yarn ply, and cam setting were varied and their effects on yarns strength loss of glass yarn were studied via measuring virgin and unravelled yarn strengths in loop form.

2. Material and methods
E-glass multi filament yarn with single-end count of 133 tex was consumed to manufacture fabrics on Brother KH-864 manual, flat weft knitting machine with a fineness of 5 gauge. Table 1 indicates the experimental plan of our study. Three input variables; knit architecture, cam setting and number of yarn ply were considered; thus sixteen (4x2x2) different samples were produced within the context of full factorial experimental design. Figure 1 indicates technical notations (needle diagrams) of the weft-knitted fabrics; and Figure 2 illustrates hand-draft drawings, and actual images of knit architectures. To quantify the damage level of various loop formation mechanisms over yarn strength; knit architectures including different loop types (plain, skip, tuck, and weft-inlay yarn) were selected.
### Table 1. Experimental plan

| Variables          | Knit architecture | Cam setting | Number of yarn ply |
|--------------------|-------------------|-------------|--------------------|
| Levels:            |                   |             |                    |
|                    | Plain loop        | Loose fabric| 2-ply              |
|                    | Skip loop         | Tight fabric| 3-ply              |
|                    | Tuck loop         |              |                    |
|                    | Weft-inlay        |              |                    |

![Knit architectures](image_url)

- Plain loop
- Skip loop
- Tuck loop
- Weft-inlay
- Knit repeat boundary

**Figure 1.** Technical notations of the knit architectures

![Hand-draft drawings and actual images of knit architectures](image_url)

**Figure 2.** Hand-draft drawings and actual images of knit architectures

After the needle passed the hooked yarn through the formerly formed loop; descending distance of the needle on the cam track is controlled by cam setting that directly specifies the size of the loop. The longer the needle descending distance is, the greater the loop size is. Cam setting is adjusted by a dial called “Tension Dial” (Figure 3). This dial is scaled from 0 to 10, and each scale being subdivided into three parts. While 0 is the shortest descending distance of the needle that corresponds the smallest loop size with the highest internal yarn tension within the loop; 10 is the longest descending distance of the needle that corresponds the largest loop size with the lowest internal yarn tension within the loop. Thus, the cam setting indirectly determines internal yarn tension within the loop; and hence the dial for cam setting is called as “Tension Dial”. Figure 4 illustrates cam tracks followed by needles and fabric structures manufactured by different tension dial numbers. We decided on two different tension dial settings; number 3 and 8, where number 3 created a tight fabric structure (with smaller loops), and number 8 created a loose fabric structure (with larger loops). The last input variable of this study was number of yarn ply that was fed to the machine through the guides. Half of the samples were produced from 2-ply yarn, while the other half from 3-ply yarn.
Figure 3. K-carriage and the tension dial on the K-carriage

| The dial setting | Cam tracks followed by needles | Fabric structure |
|------------------|--------------------------------|-----------------|
| # 10             | ![Cam tracks](image1)           | ![Fabric structure](image2) |
| # 0              | ![Cam tracks](image3)           | ![Fabric structure](image4) |

Figure 4. Tension dial settings and their corresponding cam tracks followed by needles and the resultant fabric structures (Brother Industries Ltd., 1990)

During knitting of the fabrics; 2 or 3 adjacent yarns acted together to form various loops while they were being jointly affected (damaged) by the machine components (yarn guides and needles). Additionally, yarns of knitted fabrics respond to external mechanical forces in loop form during their performance (tensile, bursting) tests, and service life. Therefore; to reveal the effect of the selected input parameters (knit architecture, cam setting and number of yarn ply) on yarn strength and to correlate yarn strength with the performance of resultant fabrics more accurately; 2-, and 3-ply unravelled and virgin yarn strengths in loop form (Figure 5) were measured according to ASTM D2256 with a gauge length of 250 mm, pretension of 0.500 cN/tex, and extension rate of 50 mm/min. Load cell with a maximum capacity of 600 N was selected. To prevent yarn slippage inside the jaws during tests; fibers at both ends of the yarns where they are grabbed by the jaws were glued by two-part epoxy (Figure 6). The crossing point of the yarns was positioned into middle of the gauge section (Figure 7). Maximum load (Newton) and the extension (mm) at maximum load were obtained from the raw data file of the machine software. Maximum load (cN) was divided by the total tex between the jaws to calculate the loop yarn strength in cN/tex unit.

Figure 5. Preparation of 2-ply and 3-ply yarns for loop strength test
3. Results and discussion

3.1. The effect of knit pattern on loop yarn strength

While unraveled yarns from skip stitch patterned fabric exhibited the highest yarn strength and unraveled yarn from weft-inlay showed the lowest unraveled yarn strength, no statistically significant difference was observed among the unraveled yarn strength of all knit pattern that proved lack of effect of knit pattern on yarn strength. Contrary to expected, unravelled yarns exhibited better strength than virgin yarn at statistically significant level (Figure 8 and Table 2). Knitting process improved loop yarn strength. Conversion of virgin yarn into the loop shape in the course of knitting process enhanced the uniform distribution of fibers in the yarn cross section that enhance the load carrying capability of unravelled yarns.

Figure 8. The effect of knit pattern on loop yarn strength

Note: The distance between top and bottom spikes of each green diamond represent the 95% confidence interval for the related origin of yarn level. Comparison circles (given on the right column) for means those are significantly different either do not intersect, or intersect slightly.
Table 2. Knit pattern versus loop yarn strength report

| Knit pattern  | n  | mean, cN/tex | sd, cN/tex | LL, cN/tex | UL, cN/tex |
|---------------|----|--------------|------------|------------|------------|
| skip stitch   | A  | 23,34        | 1,76       | 22,77      | 23,90      |
| tuck stitch   | A  | 23,31        | 2,58       | 22,49      | 24,14      |
| single jersey | A  | 23,05        | 2,22       | 22,34      | 23,76      |
| weft-inlay    | A  | 21,95        | 2,26       | 21,23      | 22,68      |
| virgin yarn   | B  | 18,43        | 2,64       | 17,85      | 19,02      |

Note: Levels not connected by the same capital letter are significantly different. n: number of measurements, sd: standard deviation, LL: lower limit, UL: upper limit. Limits are based on 95% confidence level.

3.2. The effect of cam setting on loop yarn strength

Yarns unravelled from tightly knitted fabrics exhibited slightly higher loop strength than yarns from loosely knitted fabrics; however this difference did not reach statistically significant level (at $\alpha = 0.05$ significance level) (Figure 9, Table 3). Yarns in tight fabrics have shorter loop length with smaller size and greater internal tension than yarns in loose fabrics. Short loop length and higher internal tension enhanced uniform distribution of fibers in the yarn cross section that slightly improved loop strength of unravelled yarn. Virgin yarns displayed lower loop strength than unravelled yarns that again was attributed the uniform spread and distribution of fibers over yarn cross section in case of unravelled yarns from knitted fabrics (Figure 9, Table 3).

![Figure 9. The effect of cam setting on loop yarn strength](image)

Table 3. Cam setting versus loop yarn strength report

| Cam setting  | n  | mean, cN/tex | sd, cN/tex | LL, cN/tex | UL, cN/tex |
|--------------|----|--------------|------------|------------|------------|
| tight fabric | A  | 22,96        | 2,21       | 22,47      | 23,46      |
| loose fabric | A  | 22,86        | 2,35       | 22,34      | 23,38      |
| virgin yarn  | B  | 18,43        | 2,64       | 17,85      | 19,02      |

3.3. The effect of number of yarn ply on loop yarn strength

While number of yarn ply did not affect the unravelled yarn loop strength; it affected virgin yarn loop strength at statistically significant level. 3-ply virgin yarns exhibited better strength than 2-ply yarns. Both 2-, and 3-ply unravelled yarns displayed better loop strength than their counterpart virgin yarns (Figure 10 and Table 4). Knitting process enhanced the distribution of the fibers and promoted their load bearing capability.

![Figure 10. The effect of number of yarn ply on loop yarn strength](image)
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Figure 10. The effects of number of yarn ply on loop yarn strength

Table 4. Number of yarn ply versus loop yarn strength report

| Number of yarn ply | n  | mean, cN/tex | sd, cN/tex | LL, cN/tex | UL, cN/tex |
|-------------------|----|--------------|------------|------------|------------|
| 2-ply unravelled   | A  | 80           | 22.97      | 2.00       | 22.53      | 23.42      |
| 3-ply unravelled   | A  | 80           | 22.85      | 2.53       | 22.29      | 23.42      |
| 3-ply virgin       | B  | 40           | 19.22      | 2.57       | 18.40      | 20.05      |
| 2-ply virgin       | C  | 40           | 17.65      | 2.51       | 16.84      | 18.45      |

4. Conclusion

This study investigated the effects knit pattern, cam setting, and number of yarn ply on loop strengths of unraveled yarns from weft knitted fabrics. Contrary to expectations; knit pattern and other independent input variables (cam setting and number of yarn ply) did not show statistically significant effect on unraveled yarn strength (at $\alpha = 0.05$ significance level). On the other hand, again contrary to expectations; conversion of virgin yarns into weft knitted fabrics improved loop yarn strength at statistically significant level that was attributed to uniform distribution of fibers within the yarn cross section during the knitting process. For future studies; cross sectional views of virgin and unravelled yarns will be investigated, and the comparison of other mechanical properties such as extension at maximum force (mm), time to break (s), elastic modulus (MPa), breaking work (J) will be revealed in view of the selected input parameters plus unravelled and virgin yarn perspective.

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