Fatigue behaviour of core-spun yarns containing filament by means of cyclic dynamic loading

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Abstract. The behaviour of yarns under dynamic loading is important that leads to understand the growth characteristics which is exposed to repetitive loadings during usage of fabric made from these yarns. Fabric growth is undesirable property that originated from low resilience characteristics of fabric. In this study, the effects of the filament fineness and yarn linear density on fatigue behaviour of rigid-core spun yarns were determined. Cotton covered yarns containing different filament fineness of polyester (PET) draw textured yarns (DTY) (100d/36f, 100d/96f, 100d/144f, 100d/192f and 100d/333f) and yarn linear densities (37 tex, 30 tex, 25 tex and 21 tex) were manufactured by using a modified ring spinning system at the same spinning parameters. Repetitive loads were applied for 25 cycles at levels between 0.1 and 3 N. Dynamic modulus and dynamic strain of yarn samples were analyzed statistically. Results showed that filament fineness and yarn linear density have significance effect on dynamic modulus and dynamic strain after cyclic loading.

1. Introduction

The fabrics are always under the influence of repetitive loads, especially from the motions of the knee and elbows. As a result of these repetitive forces, deformation such as bagging occurs. In this respect, fatigue behaviour of yarns that makes up the fabric is most important according to their usage areas. There are various studies on determine fatigue behaviour of yarn [1-4]. Shahbeh et al. investigate the effect of spinning parameters (core and sheath part, twist factor, pre-tension of core part) of core spun yarns and number of cyclic loads such as 100, 500 and 1000 on yarn tensile properties after cyclic loadings. They produced core spun yarns with nylon and polyester core, separately, covered with polyester/cotton, polyester and viscose sheath fibers. They stated that Taguchi method of variance analysis showed that twist factor, pre-tension on core part, number of cyclic loads and sheath materials had found to be significant except core material on the breaking strength of core-spun yarns after tensile fatigue cyclic loading [3]. Eldessouki et al. compared on physical properties of the 20 tex 100% viscose vortex yarns under dynamic loading produced on different spinning systems developed by Rieter and Murata companies. Besides, they produced 20 tex 100% viscose different yarn samples by rotor spinning system. Yarn samples were loaded for 40 cycles at levels between 0.2 and 1 N, followed by a continuous extension until the yarn breakage. And also sonic modulus of yarns were measured the velocity of the sonic pulses in the yarns at 5 kHz. Young’s modulus, maximum force, maximum
elongation, work of rupture and sonic modulus of different yarns were evaluated. It was resulted that spinning technology had no significant difference in terms of initial modulus and maximum elongation of yarns. On the other hand, a significant difference between the technologies was observed in the maximum loading and the work of rupture [2]. Dubinskaite and Milasius studied on the dynamic properties of the PA 6 and PA 6.6 carpet yarns after 10 cyclic loads. Dynamic strain, quasistatic elongation and dynamic modulus of yarns were calculated from the response of the test results at each cyclic load. It was stated that dynamic strain and quasistatic elongation of PA 6.6 is higher than PA 6. In addition dynamic modulus of PA6 yarns were found to be higher that is PA6 yarns as stronger and stiffer can be used for carpets exposed to highly traffic wear.

This study represents the fatigue behaviour of rigid core-spun yarn structure containing PET draw textured filament yarn (PET DTY) with respect to different filament fineness and yarn linear densities. For this purpose, rigid core-spun yarns were manufactured on a modified ring spinning machine at the same spinning conditions and tenacity of these yarns were conducted after determined number of cyclic loading on CRE (constant rate of extension) tensile tester. Statistical analysis was carried out to determine the significance of independent variables on response variable as well as fatigue behaviour of yarn under repeated cyclic loading.

2. Material and Method

In this study, PET DTY filaments with five different types of fineness (100d/36f, 100d/96f, 100d/144f, 100d/192f and 100d/333f) were selected among the most used commercial form of conventional microfilaments. These filaments were used as core part of combed cotton covered rigid core-spun yarns with four different yarns linear densities (37 tex, 30 tex, 25 tex and 21 tex). Cotton fibre with 30 mm length, 4.5 micronaire and 34 g/tex strength was used as sheath fiber. In this respect, yarn samples were manufactured on a modified ring spinning system which is illustrated in figure 1 and all spinning parameters were kept constant like as; 8000 rev/min spindle speed, 3.9 twist factor (αe) and 984 tex combed cotton roving linear density.

![Modified ring spinning system and core-spun yarn view](image)

**Figure 1.** Modified ring spinning system and core-spun yarn view (It may not be reproduced without permission) [5].
When the analyses of dynamic properties of yarns are taken into consideration, moduli of yarns have critical important to determine fatigue behaviour by applying repeated loads on yarns. Modulus is generally expressed as the relationship between the force applied and the resultant elongation. Dynamic modulus can be calculated with the equation (1) which is given below and shows information about fiber stiffness and resilience. We can say that the higher the dynamic modulus the stiffer the fiber, on the other hand the lower the dynamic modulus the more flexible the fiber [6].

\[ E_d = \frac{F_u - F_l}{(\varepsilon_u - \varepsilon_l) T_l} \]  

(1)

where;
- \( F_u \) : upper level of force in cN of cyclic loading,
- \( F_l \) : lower level of force in cN of cyclic loading,
- \( \varepsilon_u \) : elongation at upper level of force of cyclic loading,
- \( \varepsilon_l \) : elongation at lower level of force of cyclic loading,
- \( T_l \) : linear density of yarn in tex [6].

Dynamic strain which is fatigue behaviour of yarn that is defined as the percentage elongation under the loads in each cycle and equation can be expressed as equation (2).

\[ \varepsilon_d = \frac{\varepsilon_u + \varepsilon_l}{2} \]  

(2)

where;
- \( \varepsilon_u \) : elongation at upper level of force of cyclic loading,
- \( \varepsilon_l \) : elongation at lower level of force of cyclic loading [6].

To determine the dynamic modulus and strain of yarn samples, fatigue test was performed on Instron 5944 tensile test device applying cyclic loading and unloading on the yarn. Gauge length and speed of testing were set to 250 mm, 250 mm/min, respectively, like in accordance with BS EN ISO 2062:2009-Textiles-Yarns from packages-Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester. In order to achieve fatigue test, yarn samples were loaded for 25 cycles at levels between 0.1 and 3 N. Maximum force level was identified as 50% percent of yarn tenacity by applying force within the region of yarn’s yield point. After cyclic loading completed, test continued with continuous extension until the yarn break. Dynamic modulus of yarn samples was determined for 25\textsuperscript{th} cycles in order to analyze the final situation, so that upper and lower levels of force and corresponding elongations of 25\textsuperscript{th} cycles were used. In addition, dynamic strain was also calculated for 25\textsuperscript{th} cycles i.e. after the final cyclic loading.

Before carrying out fatigue test, the specimens were conditioned in a standard atmosphere at 20±2°C temperature and 65±4% relative humidity for 24 hours according to the standard of BS EN ISO 139:2005+A1:2011-Textiles-Standard atmospheres for conditioning and testing. To compare the significance difference between dynamic modulus and dynamic strain of yarn samples statistically, analysis of variance was performed by using SPSS package program.

3. Result and Discussion

Figure 2 illustrates dynamic modulus of rigid core-spun yarn samples with different filament fineness and yarn linear density by using equation (1) to determine after 25\textsuperscript{th} cycles of loading.
As seen in figure 2, dynamic moduli of rigid core-spun yarns with PET DTY filaments with different filament fineness as core part change from higher to lower values of yarn linear densities. The dynamic modulus values are higher at coarser yarn and it can be said that the coarser yarns are stiffer than finer ones. In general, dynamic modulus of yarn decreases from coarser to finer yarn. As the yarn is finer makes probably yarn more resilient in terms of increasing PET PDY filament percentage in the cross section. Dynamic strain of rigid core-spun yarn samples are also shown in figure 3.

![Figure 2. Dynamic modulus of rigid core-spun yarns.](image1)

![Figure 3. Dynamic strain of rigid core-spun yarns.](image2)

It is seen in figure 3 that the dynamic range increases with the increase of the PET DTY filament ratio from 37 tex to 21 tex yarn linear density. In addition, the increase in dynamic strain with respect to yarn linear density probably indicates that the deformed fibers have a high ability to return to their original state with lower residual elongation [6]. When the effect of filament fineness on dynamic strain is taken into consideration it was found to be significant. Rigid core-spun yarns with microfilament core part are found to have lower dynamic strain than conventional ones. This situation demonstrates the ability of resilience of microfilament rigid core-spun yarns are higher.
Table 1. Analysis of variance of between-subjects effects.

| Source               | Dependent Variable       | Sum of Squares | df  | Mean Square | F       | Sig.   | Partial Eta Squared |
|----------------------|--------------------------|----------------|-----|-------------|---------|--------|---------------------|
| Corrected Model      | Dynamic modulus          | 177251.722\(a\) | 19  | 9329.038    | 47.777  | .000   | .919                |
|                      | Dynamic strain           | 1007.835\(b\)  | 19  | 53.044      | 192.499 | .000   | .979                |
| Intercept            | Dynamic modulus          | 2861537.626    | 1   | 2861537.626 | 14654.805 | .000   | .995                |
|                      | Dynamic strain           | 8494.019      | 1   | 8494.019    | 30825.185 | .000   | .997                |
| Yarn linear density  | Dynamic modulus          | 164489.157    | 3   | 54829.719   | 280.800 | .000   | .913                |
|                      | Dynamic strain           | 802.558      | 3   | 267.519     | 970.840 | .000   | .973                |
| Filament fineness    | Dynamic modulus          | 3255.498     | 4   | 813.875     | 4.168   | .004   | .172                |
|                      | Dynamic strain           | 150.564      | 4   | 37.641      | 136.601 | .000   | .872                |
| Yarn linear density\*filament fineness | Dynamic modulus         | 9507.066      | 12  | 792.256     | 4.057   | .000   | .378                |
|                      | Dynamic strain           | 54.713       | 12  | 4.559       | 16.546  | .000   | .713                |
| Error                | Dynamic modulus          | 15621.020    | 80  | 195.263     | .        | .276   |                     |
|                      | Dynamic strain           | 22.044       | 80  |             | .        |        |                     |
| Total                | Dynamic modulus          | 3054410.368  | 100 |             | .        |        |                     |
|                      | Dynamic strain           | 9523.898     | 100 |             | .        |        |                     |
| Corrected Total      | Dynamic modulus          | 192872.742   | 99  |             | .        |        |                     |
|                      | Dynamic strain           | 1029.880     | 99  |             | .        |        |                     |

\(a\) R\(^2\) = .919 (Adjusted R\(^2\) = .900)
\(b\) R\(^2\) = .979 (Adjusted R\(^2\) = .974)

To determine the significant effect of filament fineness and yarn linear densities on both dynamic modulus and dynamic strain analysis of variance was performed and tests between subject effects is shown in table 1. Both filament fineness and yarn linear density have significant effect on dynamic modulus and dynamic strain. In addition, the individual effect size of filament fineness and yarn linear densities are illustrated as partial eta squared value. The effect size of yarn linear density on dynamic modulus was found to be highly significant with the value of 91.3 %. On the other hand, filament fineness has much more lower effect on dynamic modulus with 17.2%. Nevertheless, filament fineness and yarn linear densities have higher effect on dynamic strain as 87.2% and 97.3%, respectively. 91.9% value of R\(^2\) of dynamic modulus has the strong relationship with filament fineness and yarn linear density that means the better the model fits. The similar result has been observed for dynamic strain with the 97.9% value of R\(^2\).

4. Conclusion

The influence of filament fineness and yarn linear densities on dynamic modulus and dynamic strain after 25\(^{th}\) cycles of loading was investigated. It was observed that the yarn samples have significant difference in terms of dynamic modulus and dynamic strain. In general, coarser yarns have higher dynamic modulus; it can be directly affect the resilience properties of yarn negatively. Microfilament rigid core-spun yarns have lower dynamic strain which contribute the ability of resilience of yarns after repeated loading cycle. It can be concluded that both filament fineness and yarn linear density have statistically significant on dynamic modulus and dynamic strain with high relationship.
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