Predicting the Actual Strength of Open-End Spun Yarn Using Mechanical Model

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Abstract

On this journal, modeling relation of rotor speed and rotor diameter toward yarn tension on take-off nozzle has been validated by theoretical approach and numeric computation. It shows that value of yarn tension is $F = (1,4 \cdot 10^{-13}) T t n_R^2 d_R^2$ [cN]. Excessively high spinning tension always results in an intolerable increase in yarn breakage. This paper presents a comparative study of theoretical and reference-based experimental result for predicting the actual strength of open-end spinning system.

1. Introduction

According to Lawrence[1], Open-End (OE) spinning has several advantages over ring spinning, such as increased production rate, separation of twisting and winding, possibilities of full automation of yarn spinning, and elimination of speed frame and winding. Rotor spinning, friction spinning and vortex spinning systems are three major methods of yarn manufacture developed on the principle of open end spinning. According to Gunter Trommer[3], the characteristic of all OE spinning processes is the teasing out of the sliver into individual fibres, followed by reassembly of the fibres and their twisting into the end of the yarn, enabling the twist imparting and yarn winding processes to be performed independently by two different mechanisms. The essential features of the open end spinning process are thus drafting, fibre transport, fibre alignment, cleaning (if necessary), fibre condensation, twisting, yarn removal and winding[1]. Individual fibres are being twisted at the yarn peel-off point. According to Vaclav Rohlena[2] and Gunter Trommer[3], tenacity [cN] has tendency to arise until take-off nozzle point. According to Gunter Trommer[3], value of yarn tension is $(1,4 \cdot 10^{-13}) T t n_R^2 d_R^2$ [cN].

Spinning tension, which inevitably increases as rotor speed increases with constant rotor diameter in the rotor spinning process, is ultimately limited by fibre strength. Excessively high spinning tension always results in an intolerable increase in yarn breakage. Tension yarn breaks take place in the already spun yarn, normally between the take-off nozzle and take-up rollers, leaving a short, broken yarn end in the rotor groove. The cause of tension yarn breaks is always excessive spinning tension, which affects the weakest yarn point i.e. the point, between the take-off nozzle and the take-up roller. According to Gunter Trommer[3], yarn tension in the centre of the take-off nozzle should therefore not exceed from 1/10 until 1/15 of the fibre strength.

In addition to yarn quality, running performance plays a major role in evaluation of a spinning process. Running behavior is often expressed in terms of the number of yarn breaks per unit mass of yarn. According to Lawrence[1], the stability of the rotor spinning process decides whether a problem such as trash particles, foreign fibres, dust, etc., will result in a yarn break or not. Spinning stability in rotor spinning is largely influenced by the following four factors. One of those factors is Σ the numbers of fibres in the yarn cross-section. According to Gunter Trommer[3], finer fibres permit a correspondingly finer yarn count in accordance with the minimum number of around $Z > 900$ -110 fibres necessary on average in the yarn cross-section in rotor spinning.

$$(R - r)\theta' = \psi' r + R\phi' = Vd + R\phi' \quad (1)$$

$$Vd = (R - r)\theta' - R\phi' \quad (2)$$

Assuming that yarn radius (r) is much smaller than rotor radius (R), then equation (2) can be written as

$$Vd = (\theta' - \phi')R \quad (3)$$

$$Vd = (n_{\text{yarn}} - n_{\text{rotor}}) \frac{\lambda\pi}{180^\circ} R \quad (4)$$

$$Vd = \frac{(n_{\text{yarn}} - n_{\text{rotor}})}{360^\circ} \lambda\pi d \quad (5)$$

Vd= yarn speed (m/s)

$n_{\text{yarn}}, n_{\text{rotor}}$ = yarn and rotor rotation per time (1/s)

R= radius of rotor (m)

d = rotor diameter (m)

If angle of (5) is 360° , it can be written as

$$Vd = (n_{\text{yarn}} - n_{\text{rotor}}) \pi d \quad (6)$$

3. Modeling Yarn Tension on Rotor

Study analysis of yarn movement mechanic on rotor is explained on Figure 2 below. The purpose is to get a movement equation of yarn tension.

Fig.2 Yarn tension on rotor schema

Observation: Assuming that there is rotation of Oxyz framework (rotor) which is affect yarn at ϕ' , while x-axis is along with yarn movement, and it has rotation on y-axis. It causes centrifugal force which is will equalize tension force on yarn. According to Gunter Trommer[3], yarn tension increases as rotor speed increases with constant rotor diameter in the rotor spinning process.

$$\sum F = MR\phi'^2 \quad (7)$$

$$\Delta T_R = \Delta MR\phi'^2 = \zeta \Delta R R \phi'^2 \quad (8)$$

$$\Delta T = \zeta \Delta x \cdot x \phi'^2 \quad (9)$$

$$\frac{\Delta T}{\Delta x} = \zeta \cdot x \phi'^2 \quad (10)$$

$$\frac{\partial T}{\partial x} = \zeta \cdot x \phi'^2 \quad (11)$$

$$dT = \int_{x=\rho}^R \zeta \cdot x \phi'^2 dx \quad (12)$$

$$\Delta T = T_\rho - T_o = \frac{\zeta}{2} (R^2 - \rho^2) \phi'^2 \quad (13)$$

$$\frac{T_\rho}{\zeta} - \frac{T_o}{\zeta} = \frac{1}{2} (R^2 - \rho^2) \phi'^2 \quad (14)$$

$$\frac{T_\rho}{\zeta} \approx \left(\frac{1}{2} \right) (R^2 - \rho^2) \phi'^2 \quad (15)$$

$$\frac{T_\rho}{\zeta} = \text{Const} (R^2 - \rho^2) \quad (16)$$

For ; $\rho \approx 0$

$$\frac{T_\rho}{\zeta} = \frac{T_\rho}{T_{t2}} \approx \frac{1}{2} R^2 \phi'^2 \quad (17)$$

$$T_\rho \approx \frac{1}{2} T_{t2} R^2 \phi'^2 \quad (18)$$

If angular speed of rotor for one circle is $\phi' \frac{\lambda \pi}{360} = \frac{360}{360} \pi$ per minute (60 second) and unit of rotor diameter is mm (10^{-3} meter), then the Constanta for strength is by converting units to SI units as:

$$T_\rho \approx \frac{1}{2} T_{t2} R^2 \phi'^2 \left(\pi \frac{1}{60} 10^{-3} \right)^2 \quad (19)$$

$$T_\rho \approx \frac{1}{2} T_{t2} R^2 \phi'^2 (2,7.10^{-15}) \quad (20)$$

$$T_\rho \approx 1,4.10^{-15} T_{t2} R^2 \phi'^2 [N] \quad (21)$$

If we convert [N] to [cN], then the Constanta for strength is

$$T_\rho \approx 1,4.10^{-13} T_{t2} R^2 \phi'^2 [cN] \quad (22)$$

4. Result and Discussion

4.1. Predicting Yarn Strength

According to Gunter Trommer[3], yarn tension in the centre of the take-off nozzle should therefore no exceed from 1/10 until 1/15 of the fibre strength (F_F). This expression can be written as maximum permissible spinning tension.

$$F_{\max} = \frac{1}{U} F_F \quad (23)$$

According to Gunter Trommer[3], $F_{\max} = (1,4.10^{-13}) n_R^2 d_R^2 [cN]$, then

$$(1,4.10^{-13}) n_R^2 d_R^2 [cN] \leq \frac{1}{U} F_F \quad (24)$$

Assuming that samples were produced under same conditions as test result experiment by Erdem Koç *et al.* [4]. In this predicting, value of Constanta U were 10, minimum number of average in the yarn cross-section in rotor spinning (Z) 110 fibres. Then the strength test result (predicting result) is

$$F_F = F_{\max} \times Z \quad (25)$$

Strength test result (predicting approach) can be achieved as Table 3 below.

Table 3. Strength test result (predicting result)

Rotor		Predicting Result		
Diameter [mm]	Speed [rpm]	Fmax	F _F	Force yarn [cN]
32	52200	0,390633	3,906331	429,6964
32	60070	0,517301	5,173009	569,031
32	69920	0,700859	7,008593	770,9452

Table 4 below explains comparison of yarn strength value between observation and prediction. And Figure 3 shows predicted versus observed experimental yarn strength value.

Table 4. Comparison of yarn strength

Rotor		Yarn strength [cN]	
Diameter [mm]	Speed [rpm]	Predicting Result	Experimental Result
32	52200	429,6964	459.74
32	60070	569,031	489.97
32	69920	770,9452	516.79

As can be seen from Table 4 and Figure 3, the value of prediction and observed (actual) yarn strength has R² value 0,980. Therefore the prediction value is acceptable.

Fig.3 Predicted versus observed yarn strength value

4.2. Predicting Yarn Tenacity

Assuming that samples were produced under same conditions as test result experiment by Erdem Koç *et al.* [4]. In this predicting, value of Constanta U were 10, minimum number of average in the yarn cross-section in rotor spinning (Z) =110 fibres.

According to Gunter Trommer[3], $F_{\max} = (1,4 \cdot 10^{-13}) T_t n_R^2 d_R^2$ [cN], then Tt as yarn count system for Tex which is yarn samples were 100% PES and had approximately 25 tex linear density, then to achieve yarn tenacity value:

$$T_t = \frac{F_{\max}}{Tex} \quad (26)$$

Table 5. Tenacity test result (predicting result)

Rotor		Predicting Result	
Diameter [mm]	Speed [rpm]	Fmax [cN]	Tenacity [cN/Tex]
32	52200	0,390633	17.18785475
32	60070	0,517301	22.76124076
32	69920	0,700859	30.83780856

Table 6 below explains comparison of yarn strength value between observation and prediction. And Figure 4 shows predicted versus observed experimental yarn tenacity value.

Table 6. Comparison of yarn tenacity

Rotor		Yarn Tenacity [cN/Tex]	
Diameter [mm]	Speed [rpm]	Predicting Result	Experimental Result
32	52200	17.18785475	19.64
32	60070	22.76124076	21.06
32	69920	30.83780856	22.09

As can be seen from Table 6 and Figure 4, the value of prediction and observed (actual) yarn tenacity has R^2 value 0,961. Therefore the prediction value is acceptable.

Fig.4 Predicted versus observed yarn tenacity value

5. Conclusions

This modeling relation of rotor speed and rotor diameter toward yarn tension can be used to predicting yarn strength. This modeling results that yarn tension is as same as According to Gunter Trommer[3], $F = (1,4 \cdot 10^{-13}) T t n_R^2 d_R^2$ [cN].

R^2 of both yarn strength and yarn tenacity is closer to 1, therefore this prediction is acceptable and can be used to predicting yarn strength.

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