Size Effect of Interlacer

Part 3 : Formulation of Number of Tangles

Weichun Lou, Yoshiyuki Iemoto* and Shigeomi Chono**,

Faculty of Engineering, Fukui University, Fukui 910-8507, Japan.

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Abstract

In order to clarify the size effect of an interlacer and easily choose conditions to process interlaced yarns with a desired number of tangles, we made 16 interlacers with various sizes of both yarn duct diameter d and air jet nozzle diameter d_n and measured the number of tangles of interlaced raw yarn. Then the number of tangles was formulated as a function of the interlacer sizes d and d_n , the supplied air pressure p and the feed ratio F . Results obtained are as follows: (1) The polynomial combined with a Heaviside's step function expresses satisfactorily the distribution of the number of tangles, which takes maximum values as a function of p , F , d and d_n . It represents very well the distributions of the maximum number of tangles and both supplied air pressure and feed ratio which give the maximum number. (2) The maximum number of tangles does not monotonously vary with d and d_n , but the optimum values of d and d_n exist. Both the supplied air pressure and the feed ratio which give the maximum number of tangles monotonously increase with an increase in d and a decrease in d_n .

1. Introduction

When the interlacing process is applied to a multi-filament yarn, it is necessary to choose a proper set of processing conditions for the material, the thickness, the number, the cross-sectional shape, the surface state and so on of filaments in order to obtain the interlaced yarn with a desired number of tangles and a desired entanglement strength, etc. The processing conditions are the shape and size of interlacer, the yarn speed, the supplied air pressure, the feed ratio, etc. It is important to make the properties of interlaced yarn correspond quantitatively to the combination of so many conditions.

However, it is not easy to cover all conditions because there are so many conditions. In two previous papers^{[1], [2]}, hence, adopting the most basic type of interlacers of various sizes, where an air jet nozzle with a circular cross section is vertically installed to the midpoint of the yarn duct with a circular cross section, we discussed the effect of the size of an interlacer. In the first paper^[1] the number of tangles, the distance between tangling parts and the yarn motion were examined and the size of suitable interlacer for processed yarn was described. In the second paper^[2] the air pressure was measured on the yarn duct wall and the air flow in the yarn duct was discussed.

In this paper the number of tangles was correlated with the diameters of yarn duct and air jet nozzle, the supplied air pressure and the feed ratio in order to easily choose the

processing conditions under which interlaced yarns with a desired number of tangles can be made.

2. Experimental apparatus and procedure

The test yarn was polyester multi-filament raw yarn (150d/48f).

Figure 1 shows the interlacer used in this experiment. The notation d is the yarn duct diameter, l_d the yarn duct length, d_n the air jet nozzle diameter and l_g the distance between yarn guides. The air jet nozzle is vertically installed to the midpoint of the yarn duct. The yarn guides at both ends of the interlacer place the yarn in the yarn duct axis. Table 1 shows the designated numbers and the sizes of the interlacers. The sizes of l_d and l_g are proportional to the

Fig. 1 Interlacer

*Corresponding author

**Present address: Kochi University of Technology, Kochi 782-8502, Japan

Table 1 Numbers and dimensions of interlacers (unit: mm)

$d \backslash d_n$	1.0	1.2	1.4	1.7	l_d	l_g
3.4	①	⑤	⑨	⑬	17.6	37.8
3.1	②	⑥	⑩	⑭	16.3	34.9
2.8	③	⑦	⑪	⑮	14.7	31.5
2.4	④	⑧	⑫	⑯	12.5	26.8

value of d . The description of the yarn running apparatus is omitted because it is the same as in the previous paper^[1].

The experiment was carried out under the conditions that the fixed initial tension was 150 mN (1 mN = 0.102 gf), the fixed yarn speed was 200 m/min, the supplied air pressures p were 0.1 ~ 0.7 MPa (1 MPa = 10.2 kgf/cm²) at an interval of 0.1 MPa and the feed ratios F were 1 ~ 17 % at an interval of 1 %. The number of tangles was measured by eye^[1].

3. Empirical formula

The experimental values of the number of tangles will not monotonously vary as a function of the yarn duct diameter d , the air jet nozzle diameter d_n , the supplied air pressure p and the feed ratio F as shown in the next section, and take maximum values. To express the number of tangles, the following polynomial, which is mathematically the simplest function with a maximum, is used in this paper.

$$N^*(d, d_n, p, F) = \sum_{m_1=0}^M \sum_{m_2=0}^{m_1} \sum_{m_3=0}^{m_2} \sum_{m_4=0}^{m_3} C_k d^{m_1-m_2} d_n^{m_2-m_3} p^{m_3-m_4} F^{m_4}, \quad (1)$$

where N^* is a calculated value of the number of tangles, M is the highest degree, and C_k is a coefficient. The summation of the square of residual R is defined by

$$R = \sum_{j=1}^n (N_j^* - N_j)^2, \quad (2)$$

where n is a total number of the experimental data, N is an experimental value of the number of tangles, and the subscript j shows the j -th of the experimental data. The coefficient C_k is determined to minimize R .

In the meanwhile, when F is too large, a loose yarn stands at the entrance of an interlacer and finally breaks. Therefore, N suddenly changes from a bounded value to zero above a limit value of F . This limit value of F at which the interlacing process is possible is expressed by the following polynomial.

$$F^*(d, d_n, p) = \sum_{m_1=0}^M \sum_{m_2=0}^{m_1} \sum_{m_3=0}^{m_2} C_{Fk} d^{m_1-m_2} d_n^{m_2-m_3} p^{m_3}, \quad (3)$$

where F^* is a calculated value of the limit feed ratio and C_{Fk} is a coefficient. The summation of the square of residual R_F is defined by

$$R_F = \sum_{j_F=1}^{n_F} (N_{j_F}^* - N_{j_F})^2, \quad (4)$$

and the coefficient C_{Fk} is determined to minimize R_F . Here n_F is a total number of the experimental data used to calculate F^* and the subscript j_F shows the j_F -th of the data.

Taking account of the limit feed ratio, we can obtain the calculated value N_c of the number of tangles

$$N_c = N^* H(F^* - F), \quad (5)$$

where H is a unit step function: $H = 1$ for $F^* - F \geq 0$ and $H = 0$ for $F^* - F < 0$.

The highest degrees of the polynomial are described. The numbers of chosen values of the sizes d and d_n are less than those of p and F , so that the highest degree of d and d_n is decided to be less than that of p and F , and is denoted by M^* . To decide M^* and M , the average value μ_{Nm} of the absolute value of the difference between the maximum calculated value N_{cm} and the maximum experimental value N_m of the number of tangles in each interlacer

$$\mu_{Nm} = \frac{1}{n_i} \sum_{j_i=1}^{n_i} |N_{cmji} - N_{mji}|, \quad (6)$$

the average value μ_{pm} of the absolute value of the difference between the supplied air pressures p_{cm} , at which N_c takes the maximum value N_{cm} , and p_m , at which N takes the maximum value N_m ,

$$\mu_{pm} = \frac{1}{n_i} \sum_{j_i=1}^{n_i} |p_{cmji} - p_{mji}|, \quad (7)$$

the average value μ_{Fm} of the absolute value of the difference between the feed ratios F_{cm} , at which N_c takes the maximum value N_{cm} , and F_m , at which N takes the maximum value N_m ,

$$\mu_{Fm} = \frac{1}{n_i} \sum_{j_i=1}^{n_i} |F_{cmji} - F_{mji}|, \quad (8)$$

and the average value μ_N of the absolute value of the difference between all calculated values N^* and all experimental values N

$$\mu_N = \frac{1}{n} \sum_{j=1}^n |N_j^* - N_j|, \quad (9)$$

are introduced, where n_i is the total number of the interlacers used in this experiment: $n_i = 16$. The above average values for $M = 3 \sim 5$ and $M^* = 1 \sim 3$ are indicated in Tables 2 ~ 5. From Tables 2 ~ 4 the average values of μ_{Nm} , μ_{pm} and μ_{Fm} , which relate to the maximum number of tangles in each interlacer, are large when M and M^* are small, do not monotonously decrease even when M and M^* are increased, and take minimum values when $M = 4$ and $M^* = 2$. On the other hand, it is seen from Table 5 that the calculated value at the measurement point agrees better with the experimental value as the highest degrees are large. However, as the highest degrees are large, the degree of the agreement of the maximum calculated number of tangles, which appears except at the measurement points in most cases, with the maximum experimental number of tangles becomes worse as shown in Tables 2 ~ 4. This is because the calculated value of the polynomial vibrates except at the measurement points. On the other hand, when the highest degrees are reduced, the degree of the agreement of the calculated value with the experimental value is low at the measurement points, though the calculated value does not vibrate. As a result, $M = 4$ and $M^* = 2$ are adopted as the highest degrees of the empirical formula in this study because the formula

Table 2 Values of μ_{Nm} (unit: m^{-1})

$M \backslash M^*$	3	4	5
1	7.6	5.1	4.3
2	3.6	1.6	3.1
3	3.6	3.0	1.9

Table 3 Values of μ_{pm} (unit: MPa)

$M \backslash M^*$	3	4	5
1	0.05	0.05	0.05
2	0.05	0.02	0.04
3	0.05	0.04	0.03

Table 4 Values of μ_{Fm} (unit: %)

$M \backslash M^*$	3	4	5
1	2.3	2.1	2.1
2	1.4	0.3	1.1
3	1.4	0.9	1.1

Table 5 Values of μ_N (unit: m^{-1})

$M \backslash M^*$	3	4	5
1	7.2	6.4	6.1
2	5.4	4.1	3.7
3	5.4	3.8	2.8

represents the experimental values of the number of tangles in the region of the high number of tangles rather than in the entire region.

4. Results and discussion

4.1 Number of tangles

Figure 2 shows equi-value lines of the number of tangles in the 16 interlacers for various supplied air pressures p and feed ratios F . These lines including a line of $20 m^{-1}$ were drawn at an interval of $5 m^{-1}$ in the range of $110 \sim 70 m^{-1}$ and an interval of $10 m^{-1}$ in the range of $70 \sim 40 m^{-1}$. The numbers in the figures mean the number of tangles in a unit of m^{-1} . The left figures show the experimental value of N and the equi-value lines were drawn by interpolation of measured values. The experimental value of the limit value of F at which a yarn can be interlaced was decided under the condition that it varied smoothly with an increase in p , and plotted by the symbol $\circ$. The right figures show the calculated value of N_c obtained from Eq. (5).

Figure 2 shows that the calculated values agree well with the experimental values. Therefore, Eq. (5) excellently shows the distribution of the number of tangles which takes

a maximum value as a function of p and F .

Interlaced yarns can be produced even at an larger value of F as d is large and/or d_n is small. This is because the air frictional force on the yarn is small owing to slow air flow in the axial direction and the yarn does not stand at the entrance of the interlacer. However, when the result in the interlacer with $d = 3.1$ mm is seen in detail, an exception is seen for changing d_n . Tangling and opening parts are generated in the interlacer ⑥ ($d_n = 1.2$ mm) even at a larger value of F than those in the interlacer ② ($d_n = 1.0$ mm). In the interlacer ⑥ a yarn rarely stands at the entrance of the interlacer and can be interlaced even at a comparatively large value of F because the maximum number of tangles becomes largest among the 16 interlacers and then the yarn tension grows^[3]. The range of F at which a yarn can be interlaced is the widest at a medium value of p . The value of p at which the range of F is the widest decreases with an increase in d_n .

When raw yarns are compared with false-twist textured yarns^[4], raw yarns change rapidly from the state of the maximum number of tangles to the impossible state of the process with an increase in F , while false-twist textured yarns are so easy to elongate along the yarn axis that the limit value of F is not remarkable.

To examine the degree of the agreement of Eq. (5) with experimental values in each interlacer, Table 6 shows the average value μ_i of the absolute value of the difference between calculated value N_c and experimental value N in each interlacer

$$\mu_i = \frac{1}{n_{it}} \sum_{j_i=1}^{n_{it}} |N_{cjt} - N_{jt}|, \quad (10)$$

where n_{it} is a total number of data in each interlacer. The value of μ_i does not show such a remarkable tendency as monotone, maximum or minimum with increasing d and d_n , so that superiority or inferiority of Eq. (5) can not be discussed for changing d and d_n .

Table 6 Values of μ_i (unit: m^{-1})

d_n mm $\backslash$ d mm	1.0	1.2	1.4	1.7
3.4	3.2	3.5	2.8	1.9
3.1	6.2	4.5	3.5	4.4
2.8	5.4	6.4	5.6	3.5
2.4	3.7	3.9	4.5	3.5

4.2 Maximum number of tangles

Figure 3 shows the equi-value lines of the maximum number of tangles in the interlacers with various values d and d_n when p and F are changed. The numbers in the figure are a maximum number of tangles in a unit of m^{-1} . The left figures show the experimental value of N_m . The right figures show the equi-value lines of the maximum value of N_{cm} calculated from Eq. (5) in each interlacer. Equation (5) can excellently represent the distribution of the maximum

(a) Interlacer ① with $d_n = 1.0$ mm and $d = 3.4$ mm

(b) Interlacer ② with $d_n = 1.0$ mm and $d = 3.1$ mm

(c) Interlacer ③ with $d_n = 1.0$ mm and $d = 2.8$ mm

(d) Interlacer ④ with $d_n = 1.0$ mm and $d = 2.4$ mm

Fig. 2 Number of tangles

(e) Interlacer ⑤ with $d_n = 1.2$ mm and $d = 3.4$ mm

(f) Interlacer ⑥ with $d_n = 1.2$ mm and $d = 3.1$ mm

(g) Interlacer ⑦ with $d_n = 1.2$ mm and $d = 2.8$ mm

(h) Interlacer ⑧ with $d_n = 1.2$ mm and $d = 2.4$ mm

Fig. 2 (continued) Number of tangles

(i) Interlacer ⑨ with $d_n = 1.4$ mm and $d = 3.4$ mm

(j) Interlacer ⑩ with $d_n = 1.4$ mm and $d = 3.1$ mm

(k) Interlacer ⑪ with $d_n = 1.4$ mm and $d = 2.8$ mm

(l) Interlacer ⑫ with $d_n = 1.4$ mm and $d = 2.4$ mm

Fig. 2 (continued) Number of tangles

(m) Interlacer ⑬ with $d_n = 1.7$ mm and $d = 3.4$ mm

(n) Interlacer ⑭ with $d_n = 1.7$ mm and $d = 3.1$ mm

(o) Interlacer ⑮ with $d_n = 1.7$ mm and $d = 2.8$ mm

(p) Interlacer ⑯ with $d_n = 1.7$ mm and $d = 2.4$ mm

Fig. 2 (continued) Number of tangles

number of tangles.

The maximum number of tangles does not monotonously change for changing d and d_n , and the optimum values of d and d_n exist. The maximum number of tangles of 114.5 m^{-1} was measured in the interlacer ⑥ ($d_n = 1.2 \text{ mm}$ and $d = 3.1 \text{ mm}$) of the 16 interlacers used in this experiment. This maximum number of tangles in the raw yarn is smaller than the maximum number of tangles $126.5 \text{ m}^{-1[1]}$ in false-twist textured yarns obtained in the interlacer with $d_n = 1.4 \text{ mm}$ and $d = 2.8 \text{ mm}$. Raw yarns are more difficult to interlace than false-twist textured yarns.

Figure 4 shows the equi-value line of the supplied air pressure at which the maximum number of tangles is generated in each interlacer. The numbers in the figures represent the supplied air pressure in a unit of MPa. The left figures show the experimental value of p_m , and the right

figures the calculated value of p_{cm} . Equation (5) can excellently represent the distribution of the supplied air pressure at which the maximum number of tangles is generated in each interlacer. These supplied air pressures monotonously increase with an increase in d and/or a decrease in d_n and are in the range of $0.35 \sim 0.5 \text{ MPa}$ as shown in Figs. 4 and 3.

Figure 5 shows the equi-value lines of the feed ratio at which the maximum number of tangles is generated in each interlacer. The numbers in the figure represent the feed ratio in a unit of %. The left figures represent the experimental value of F_m , and the right figures the calculated value of F_{cm} . Equation (5) can excellently show the distribution of the feed ratio at which the maximum number of tangles is generated in each interlacer.

The feed ratio, at which the maximum number of tangles

Fig. 3 Maximum number of tangles

Fig. 4 Supplied air pressure giving maximum to number of tangles

Fig. 5 Feed ratio giving maximum to number of tangles

is generated, increases with an increase in d and/or a decrease in d_n and its range is 7 ~ 11 % as shown in Figs. 5 and 3.

As a result, it can be confirmed that the processing condition to obtain the interlaced yarn with a desired number of tangles can be easily chosen using the empirical formula driven here, which excellently represents the number of tangles.

5. Conclusions

In order to clarify the effect of the size of an interlacer, and to easily choose the processing condition to make the interlaced yarn with a desired number of tangles, interlacers with different yarn duct diameters d and air jet nozzle diameters d_n were manufactured and the number of tangles of interlaced raw yarns was measured. Next, the number of tangles was formulated as a function of the sizes of the interlacers, the supplied air pressure p and the feed ratio F . Results obtained are as follows:

(1) Equation (5), constituted by the polynomial of degree 2 with respect to d and d_n and of degree 4 with respect to p and F and the unit step function, can excellently calculate the distribution of the number of tangles which takes the maximum value with increasing p , F , d , and d_n . Moreover, Eq. (5) can excellently predict the distributions of the maximum number of tangles, and both p and F at which the

maximum number of tangles is generated.

(2) The maximum number of tangles does not monotonously change with d and d_n , and the optimum values exist in d and d_n . The supplied air pressure and the feed ratio, at which the maximum number of tangles is generated, monotonously increase with an increase in d and/or a decrease in d_n .

(3) When raw yarns are compared with false-twist textured yarns, with increasing F , raw yarns change rapidly from the state of the maximum number of tangles to the impossible state of interlacing process, while false-twist textured yarns do not show a remarkable limit value of F . The maximum number of tangles of raw yarns is smaller than that of false-twist textured yarns; the interlacing process of raw yarns is more difficult than that of false-twist textured yarns.

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