The Influence of Loop Length on Microcapsule Loading Capability of Interlock Knitted Fabric

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Abstract

Microcapsule application is a modern method of finishing functional textiles. Microcapsule loading capability of fabric, a very important value for evaluating the efficiency of this method, depends on many factors including fabric structural parameters. In this study, the influence of loop length on microcapsule loading capability of Interlock knitted fabrics was investigated. Eudragit RSPO microcapsules containing Ibuprofen were made by solvent evaporation method. Five levels of loop length on Cotton Interlock knitted fabric were 2.81, 2.83, 2.87, 2.96, 3.05 mm and three levels of this on CVC 60/40 Interlock knitted fabric were 2.65, 2.80, 2.95 mm (both series of fabrics had yarn count of Ne40/1). Microcapsules were impregnated onto fabric by wet coating. Microcapsule loading capability of fabric was determined by the change in mass of fabric after microcapsule impregnation. The regression equation expressing the influence of loop length on microcapsule loading capability was approached by least squares method. The results showed that for both series of fabrics, microcapsule loading capability depended on loop length by a quadratic function with high coefficient of determination (0.9÷1).

Keywords: Interlock knitted fabric, loop length, surface density, porosity, microcapsules.

1. Introduction

Application of microcapsules in finishing functional textiles has been developed strongly recent years. Microcapsules are tiny particles, which range in size from one micron to few millimeters. They contain solid, liquid or gaseous active ingredients (the core) packed within a second material (polymer shell) for the purpose of shielding the active ingredients from the surrounding environment [1, 2]. Microcapsule loading capability of fabric (MLC) is defined as the microcapsule content that was impregnated onto fabric and is often expressed by the weight percentage of microcapsule to non-treated fabric [3-9]. This value is very important because it has significant impact on active release configuration of fabric [10-12].

In weaving field, there have been some studies about the influence of woven structural parameters on microcapsule loading capability of fabric. It was concluded from these studies that the type of fiber [3, 8], the yarn count [8, 13], the woven structure and the weft yarn density [7, 13] strongly affected the quantity of microcapsule on fabric. In knitting field, there still has been little information on this issue. C. D Huong et al. [9] stated that microcapsule loading capability of knitted fabric varied with loop length. This value was inversely proportional to loop length in Rib fabric and proportional to loop length in Interlock fabric. But until now, there haven't been any equations that describe the relationship between loop length and microcapsule loading capability of knitted fabric. Such equations are really necessary for design process of functional textiles using microcapsules.

Loop length (l), the total length of a stitch, is the most important structural parameters of knitted fabric because it can be controlled directly in knitting machine and it significantly contributes to the structure of final textile product. The surface density and porosity are the two of structural parameters that depend closely on loop length with the same knitting material. The surface density (S) is defined as the number of stiches in one side of fabric per unit area. In fully relaxed Interlock fabric, the relationship between surface density and loop length was observed as below [14, 15]:

$$S = \frac{K_1}{l^2} \qquad (1)$$

In which, K_1 was the numerical constant. This value was independent of fiber type, yarn count and loop length but dependent on yarn twist. It was reported that if the unit of S and l respectively were stitches/cm^2 and mm then the value of K_1 in wool Interlock fabric was around 21000 and 19100 corresponding to yarn twist of 6.3 and 4.0 (twists/cm) [14].

The porosity of fabric (P %) is the ratio of void space within fabric to the total volume of fabric. This

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was often determined by the calculation below [16-19]:

$$P = 100 \times \left[1 - \frac{M}{t\rho}\right] \quad (2)$$

In which:

M: the mass per unit area of fabric (mg/mm^2)

t: the thickness of fabric (mm)

ρ: the fiber density (mg/mm^3)

The mass per unit area of fabric M can be calculated by:

$$M\ (mg/mm^2) = S' \times m \quad (3)$$

S' is the number of stitches per mm^2 and m is the mass of one stitch (mg). If the surface density S and the loop length l are respectively measured by number of stiches/cm^2 and mm then we have:

$$S' = \frac{S}{50} \quad (4)$$

$$m = \frac{l}{N_m} \quad (5)$$

with N_m is the yarn count in fabric.

Combining equations (3-5), we have:

$$M\ (mg/mm^2) = \frac{S \times l}{50 \times N_m} \quad (6)$$

Besides, the thickness t of Interlock fabric at the fully relaxed state was reported to be independent of loop length [14]. According to manufacturing experiences in knitting technology, t ≈ 4d for normal Interlock structure (with d is the yarn diameter) [20]. Therefore, it can be deduced from equations (1-2) and (6) that:

$$P = 100 \times \left[1 - \frac{K_1}{200 \times l \times N_m \times d \times \rho}\right] \quad (7)$$

Equation (7) shows that for certain type of knitting yarn (with yarn count N_m, yarn diameter d and fiber density ρ), porosity of Interlock knitted fabric will be proportional to loop length.

The present study aimed to evaluate the influence of loop length (l) on microcapsule loading capability (ML) of Interlock knitted fabric. The equation that describes this effect was built on the basis of the change in fabric surface density (S) and porosity (P) when varying the loop length.

2. Material and Experimental method

2.1. Material

2.1.1. Chemicals for microencapsulation

Ibuprofen, Miglyol 812 and Eudragit RSPO were respectively supplied by Basf, Sasol and Evonik Industry (Germany). Saponin from Quillaja bark (Sapogenin content 20 ÷ 35 %) was purchased from Sigma Aldrich and Ethyl acetate with purity of 99.9 % was from Carlo Erba. All chemicals have been used as providing without any more purification.

2.1.2. Interlock knitted fabrics

Interlock fabrics were knitted and bleached at Doximex Knitting Company. They had yarn count of Ne40/1 and different levels of loop length as below:

- Cotton Interlock fabrics had 5 levels of loop length 2.81, 2.83, 2.87, 2.96 and 3.05 mm. The fiber density of Cotton $\rho_{cotton} = 1.52\ mg/mm^3$.
- CVC Interlock fabric (40 % Polyester/ 60% Cotton) had 3 levels of loop length 2.65, 2.80 and 2.95 mm. The fiber density in this case was considered as the combination of Polyester ($\rho_{Polyester} = 1.30\ mg/mm^3$) and Cotton ($\rho_{cotton} = 1.52\ mg/mm^3$) with weight ratio of 40/60. Therefore, the fiber density in CVC yarn $\rho_{CVC} = 1.43\ mg/mm^3$.

2.2. Experimental method

2.2.1. Microencapsulation

Ethyl acetate solution containing Ibuprofen, Miglyol 812 and Eudragit RSPO was dripped to Quillaja Saponin aqueous solution under blade stirring. The evaporation of ethyl acetate at reduced pressure was initiated after the emulsification. Microcapsules collected after 5 hours were washed three times with distilled water and then dried under vacuum at 25°C for 24 hours.

The average diameter and the size distribution of microcapsules were determined by laser difractometry using a Particle Size Analyzer LA-950 HORIBA.

2.2.2. Determination of fabric structural parameters

All fabrics mentioned in the Part 2.1.2 were fully relaxed before determination of structural parameters.

- The surface density S (stitches/cm^2) was calculated by equation (8) below:

$$S\ (\text{number of stitches}/cm^2) = \frac{Weft\ density \times Warp\ density}{100} \quad (8)$$

with weft density (wales/100mm) and warp density (courses/100mm) were measured according to the testing standard TCVN 5794:1994.

- The width A (mm) and the height B (mm) of a loop was calculated by $\frac{100}{Weft\ density}$ and $\frac{100}{Warp\ density}$ respectively.
- The porosity P (%) was calculated by equation (2) in which mass per unit area M (mg/mm^2) and the

thickness of fabric t (mm) were measured according to the testing standard TCVN 8042:2009 and TCVN 5071:2007, respectively. The value of fiber density ρ (mg/mm^3) was mentioned in the Part 2.1.2.

2.2.3. Finishing of fabrics with microcapsules

The suspension of microcapsules in distilled water was coated onto fabrics by experimental blade coating equipment Mini Coater of Dealin Starlet Co., Ltd (Korea). Coating parameters were as below:

- The dimension of fabric sample: 20 cm x 20 cm.
- The concentration of microcapsules in distilled water: 24 mg/ml.
- The distance between coating blade and fabric surface: 0.5 mm.
- The coating speed: 40 mm/s.

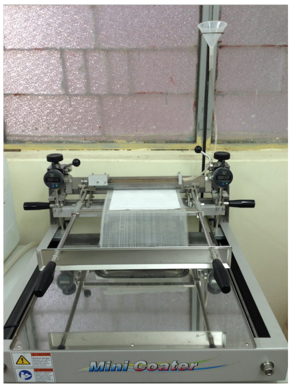

Fig. 1. Experimental coating equipment Mini Coater

Microcapsule coated fabrics were dried under vacuum until totally dry.

2.2.4. Determination of fabric microcapsule loading capability

Microcapsule loading capability of fabric was expressed by MLC (%), which was calculated as below:

$$MLC\ (\%) = \frac{M_2 - M_1}{M_1} \times 100\% \quad (9)$$

With M_1 and M_2 were the weights of fabric sample before and after the finishing process, which were determined by the electronic scale OHAUS PA413 (410g x 0.001g) after being restored in standard atmospheres for conditioning and testing (ISO 139:2005).

Microcapsule distribution on fabric surface was observed by scanning electron microscope JEOL JSM-7600F (USA) under the condition of 2 kV, LM mode and WD 8.0 mm.

2.2.5. Building equations describing the relationship between microcapsule loading capability and loop length

Regression equations expressing the relationship between microcapsule loading capability and fabric structural parameters (surface density, porosity, loop length) were built by least squares method using the software Microsoft Excel 2010.

3. Result and discussion

The value of microcapsule loading capability (MLC) of fabrics having different loop length (l) was shown in the following Fig.s, in which each value of MLC was the average of triplicated samples:

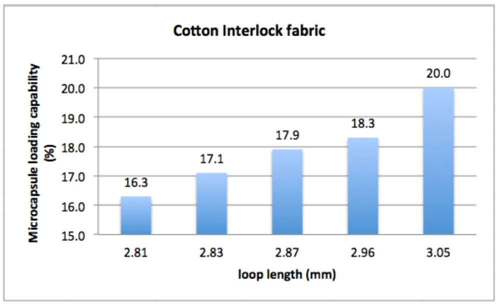

Fig. 2. Influence of loop length on microcapsule loading capability of Cotton Interlock fabrics

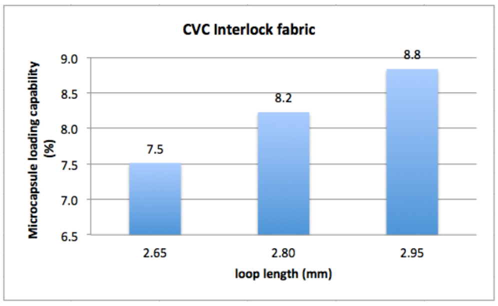

Fig. 3. Influence of loop length on microcapsule loading capability of CVC Interlock fabrics

It could be confirmed from Fig.s 2-3 that microcapsule loading capability obviously depended on loop length in Interlock fabrics. For both Cotton and CVC fabric, microcapsule loading capability were proportional to loop length. The value of MLC was 16.3, 17.1, 17.9, 18.3 and 20.0 % corresponding to loop length of 2.81, 2.83, 2.87, 2.96 and 3.05 mm in Cotton fabrics. Similarly, this value was 7.5, 8.2 and 8.8 % corresponding to loop length of 2.65, 2.80 and 2.95 mm in CVC fabrics. At the same value of loop length (2.95÷2.96 mm), Cotton fabric could load twice as many microcapsules as CVC fabric could. This may be due to the higher water adsorption of Cotton fabrics than CVC ones.

The proportional relationship here was similar to the result of C. D. Huong et al. [9] and it could be explained as follows by the change in surface density and porosity of fabric that occurred when varying the loop length.

Firstly, it should be noted that in blade coating technique, the pressure exerting on microcapsules was negligible in the direction perpendicular to the fabric surface. Therefore in case of this study, fabric surface density was an important factor that influenced the amount of microcapsules could go inside the fabric structure. According to equation (1), the increase in loop length lowered the surface density of fabric, so more microcapsules could get deep into Interlock structure instead of being loosely kept on fabric surface and easier to removed by coating blade. In fact, the measured values of weft density, warp density and surface density of fabric samples were as in Fig.s 4-5:

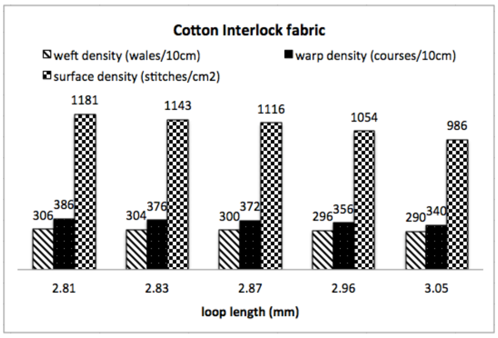

Fig. 4. Influence of loop length on weft density, warp density and surface density of Cotton Interlock fabric

It was shown in Fig. 4 that in Cotton Interlock fabric, the increase in loop length created a clear reduction in both weft density and warp density. The weft density was 306, 304, 300, 296, 290 (wales/10cm) and the warp density was 386, 376, 372, 356, 340 (courses/10cm) corresponding to loop length of 281, 283, 287, 296 and 305 mm. Consequently, the surface density (the product of weft and warp density) decreased obviously from 1181 to 986 (stitches/cm^2) when loop length went up from minimum (281 mm) to maximum value (305 mm).

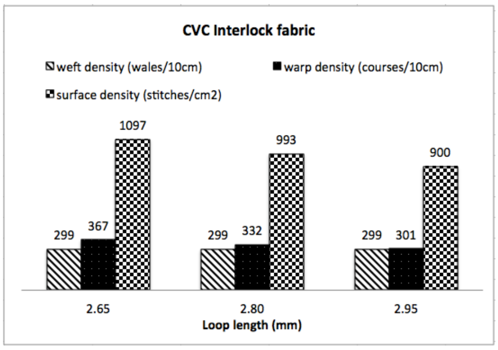

Fig. 5. Influence of loop length on weft density, warp density and surface density of CVC Interlock fabric

A little different from Cotton fabric, Fig. 5 revealed that when loop length of CVC Interlock fabric increased in order of 2.65, 2.80 and 2.95 mm, the weft yarn density didn't change while the warp density was in descending order of 367, 332 and 301 (courses/10cm). Therefore, surface density also came down with the increase in loop length in case of CVC fabric.

SEM images of CVC Interlock fabrics after microcapsule coating process also helped reveal the influence of loop length on the amount of microcapsules that could go inside the fabric structure. Fig.s 6a-c showed that microcapsules were successfully coated onto fabrics and almost of them had spherical shape with diameter of around 20 ÷ 30 µm.

A part of microcapsules settled on the fabric surface while the rest was restored deep inside the fabric structure at the gap between yarns and fibers. However, the distribution of microcapsules was remarkably different between three levels of loop length. The fabric with highest loop length of 2.95 mm could load the highest content of microcapsules (8.8 %, as in Fig. 3), but the number of microcapsules on fabric surface (Fig. 6c) were obviously lower than in fabrics with loop length of 2.80 mm (Fig. 6b) and 2.65 mm (Fig. 6a).

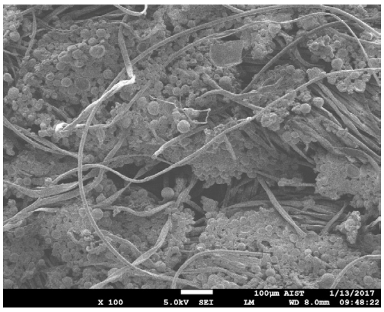

Fig. 6a. Microcapsule-contained CVC fabric with loop length of 2.65 mm

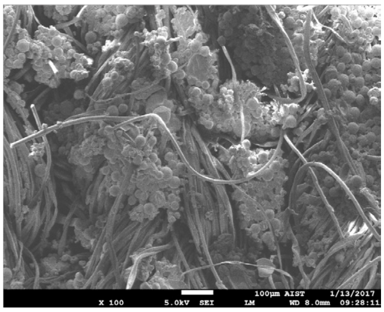

Fig. 6b. Microcapsule-contained CVC fabric with loop length of 2.80 mm

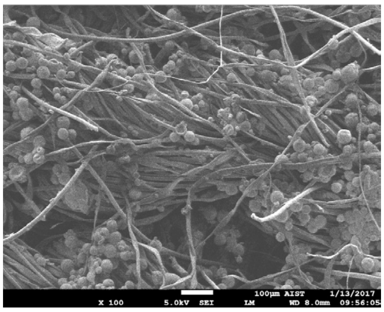

Fig. 6c. Microcapsule-contained CVC fabric with loop length of 2.95 mm

This meant microcapsules could more easily get into the structure of fabric with higher loop length because of lower fabric surface density. This is the reason for higher microcapsule loading capability in fabric with higher loop length.

Alongside with surface density, the change in porosity of fabrics when varying the loop length also contributed to the change in microcapsule loading capability. It could be seen in Fig.s 6a-c and be measured experimentally (part 2.2.2) that the CVC fabrics had loop width of around 330 µm and loop height of around 270 ÷ 330 µm. Similarly, the loop width and loop height of Cotton fabric were around 330 ÷ 345 and 260 ÷ 295 µm. Because the average diameter of microcapsules determined by laser difractometry approximated 22 µm, which agreed with SEM observation in Fig.s 6a-c, so a certain amount of microcapsules could pass through the fabric surface and be restored inside Interlock structure. According to equation (7), the porosity of Interlock fabric was proportional to loop length. Experimental measurements also confirmed this trend.

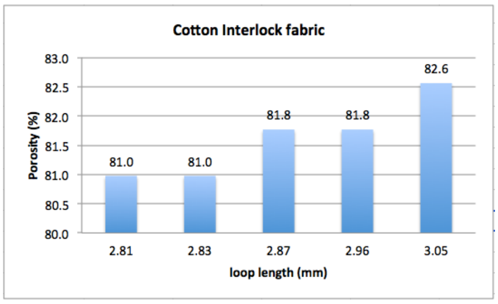

Fig. 7. Influence of loop length on porosity of Cotton Interlock fabric

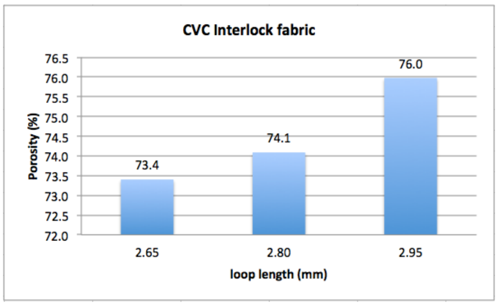

Fig. 8. Influence of loop length on porosity of CVC Interlock fabric

It could be concluded from Fig.s 7-8 that for both Cotton and CVC fabrics, increasing loop length made the porosity higher, so fabric could keep more microcapsules.

As a result, within the scope of this research, the combination of decreased surface density and increased porosity due to the increase of loop length made higher microcapsule loading capability of Interlock knitted fabrics. Furthermore, according to equations (1) and (7), the surface density was proportional to $\frac{1}{l^2}$ and the porosity was inversely proportional to $\frac{1}{l}$ so quadratic functions that described the relationship between microcapsule loading capability MLC and the reciprocal of loop length $\frac{1}{l}$ were approached by least squares method as below:

- Cotton Interlock fabric:

$$MLC = -51.109 \times \frac{1}{l^2} - 80.637 \times \frac{1}{l} + 51.791 \quad (10)$$

Coefficient of determination $R^2 = 0.94$

- CVC Interlock fabric:

$$MLC = -51.190 \times \frac{1}{l^2} + 2.237 \times \frac{1}{l} + 13.959 \quad (11)$$

Coefficient of determination $R^2 = 1$

(In which, MLC and l were respectively expressed by % and mm).

In this study, the coating parameters and the value of yarn count were similar for both fabrics, so the differences in coefficients of equations (10) and (11) could be contributed by some yarn structural parameters such as yarn twist, yarn diameter and type of fiber.

4. Conclusion

This study was concentrated on the influence of loop length on microcapsule loading capability of Interlock knitted fabrics. For both Cotton and CVC Interlock fabrics, increasing in loop length made the surface density of fabric lower and the porosity of fabric higher. The combination of these two phenomena resulted in higher microcapsule loading capability in fabric. Especially, the microcapsule loading capability depended on loop length by quadratic function with high coefficient of determination. The regression equation for Cotton Interlock fabric was $MLC = -51.109 \times \frac{1}{l^2} - 80.637 \times \frac{1}{l} + 51.791$ with $R^2 = 0.94$. For CVC Interlock fabric, $MLC = -51.190 \times \frac{1}{l^2} + 2.237 \times \frac{1}{l} + 13.959$ with $R^2 = 1$.

Acknowledgments

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