Development of High Strength and High Thermal Conductive Fixing-Film Sleeve

Shingo NAKAJIMA*, Yusuke UCHIBA, Naoki ONMORI, Yoshimasa SUZUKI, Jun SUGAWARA, Akira MIZOGUCHI and Kazuhiro KIZAWA

To meet the growing market demand for energy-saving business machines, Canon Inc. developed on-demand power-effective laser beam printers (LBPs) using their new toner-fixing method. Since 1993, Sumitomo Electric has manufactured fixing-film sleeves, indispensable components for the LBPs. Recently, the authors have developed an advanced fixing-film sleeve applicable to high-speed printing systems. This sleeve is made of composite materials consisting of highly thermal conductive carbon nanofiber and tough polyimide resin. In this paper, the authors report the development of the sleeve in detail.

Keywords: laser beam printers, fixing-film sleeves, polyimide, carbon nanofiber

1. Introduction

Saving energy consumption to decrease negative environmental impact is an important factor for electronic equipment, and office automation apparatus is no exception. In laser beam printers (hereinafter, LBPs), about 70% of power is consumed by toner-fixing devices. From the viewpoint of energy-saving, it is important to decrease power consumption in standby mode which accounts for a majority of power consumption by toner-fixing devices. For metal roller-fixing method (**Fig. 1-a**), a fixing roller is heated around 180˚C by a halogen heater placed in the roller. The toner images are fixed when they passing between the fixing roller and pressure roller heated by the halogen heater. Therefore, it is necessary to keep the fixing roller heated (standby mode) to shorten the time for the aforementioned process, and accordingly the amount of power consumption grows (**Fig. 2** quick mode). Without preheating, the amount of power consumption can be reduced, but, in return, the printing time increases (**Fig. 2** energy-saving mode). To balance these two factors: energy saving and time saving, Canon Inc. developed an on-demand fixing method. The on-demand fixing method can transmit heat generated by a ceramic heater directly to a toner through a polyimide film of tens of μm thickness with small thermal capacity. Therefore, the on-demand fixing method can minimize the preparation time to start printing with reduced power consumption compared to the roller-fixing method (**Fig. 1-b, 2**) [1]. Sumitomo Electric Industries, Ltd. produces polyimide fixing-film sleeves (hereinafter fixing-film sleeves), which are tubings coated with fluorocarbon resin to prevent the toner from adhering to the surfaces of the sleeves. For high-speed printing systems now in use, it is necessary to decrease thermal capacity of the fixing-film sleeves by reducing their thickness, or to improve the thermal conductivity, without compromising the film strength. To this end, we have developed further advanced fixing-film sleeves applicable to high-speed printing systems. These sleeves are made of composite materials composed of highly thermal conductive carbon nanofiber and tough polyimide resin. Here, we report the development of the sleeves in detail.

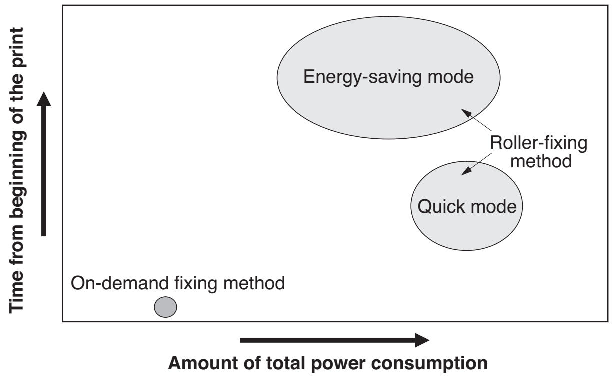

Fig. 2. Relation between time from beginning of the print and amount of total power consumption

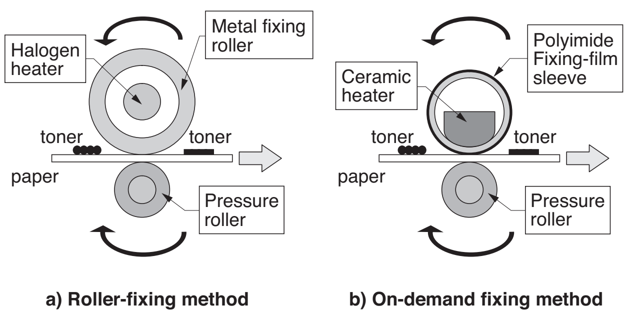

Fig. 1. Structure comparison between the roller-fixing method and the on-demand fixing method

2. Background

For fixing-film sleeves, it is necessary to have twist strength to endure the twisting force in the circumferential direction in case of paper jamming, and thrust strength against foreign bodies such as staples (**Fig. 3**). In addition, long-term heat resistance to endure heating at 200°C or more by the ceramic heater is also needed. To meet these requirements, polyimide resin, which has excellent twist strength, thrust strength and heat-resistance, is used as the basic material of fixing-film sleeves. **Table 1** shows the composition of the conventional fixing-film sleeves that Sumitomo Electric has produced for Canon Inc. since 1996. These fixing-film sleeves are made from polyimide resin mixed with boron nitride (BN) filler to be applied to high-speed printing machines (16 papers/minute) which came into use after low-speed machines (4 papers/minute)[(2)]. Since 2006, we have seen an increasing demand for advanced fixing-film sleeves which are applicable to further high-speed printing systems (35 papers/minute).

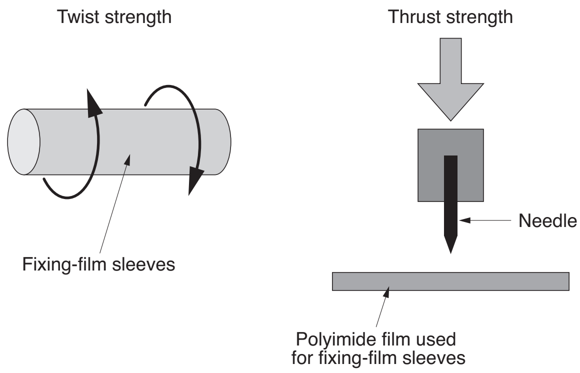

Fig. 3. Twist strength and thrust strength

Table 1. Composition of the conventional fixing-film sleeves

Name	Function	Thickness (μm)	Material
Top layer	Toner adhesion control to fixing-film sleeves	10	Fluorocarbon + carbon
Primer layer	Bonding of top layer and base layer Inducement of static electricity to earth	4	Fluorocarbon + bonding element + carbon
Base layer	Twist strength and thrust strength	67	Polyimide + BN

3. Thermal Conductivity Improvement of Fixing-Film Sleeves

3-1 Examination of thermal conductivity improvement method

It is necessary to quickly transmit the heat generated by the ceramic heater to the toner in order to increase the printing speed of LBPs. For this purpose, it is essential to improve the thermal conductivity of fixing-film sleeves.

We first considered increasing the quantity of BN used as thermal conductive filler to improve the thermal conductivity, however, it resulted in a decrease in tensile strength (**Fig. 4**). Therefore, we decided to improve the thermal conductivity of fixing-film sleeves using filler whose thermal conductivity is higher than that of BN, eliminating the need to increase the quantity of filler.

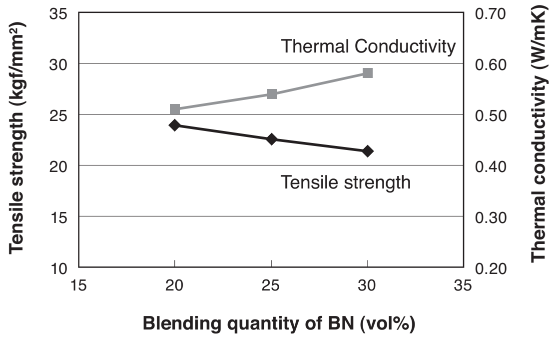

Fig. 4. Relation among BN blending quantity, tensile strength, and thermal conductivity

3-2 Selection of thermal conductive filler

We selected suitable filler for thermal conductivity improvement in the way describe below.

(1) Thermal conductivity measurement

The thermal conductivity was calculated from the thermal diffusivity measured by a periodic-heating method. The thermal conductivity λ, which works in the direction of the thickness of a fixing-film sleeve, was calculated using equation (1). In this equation, where thermal diffusivity is α, density is ρ and specific heat is Cp.

$$\lambda=\rho\cdot Cp\cdot\alpha \quad\cdots\cdots(1)$$

(2) The result of thermal conductivity measurement

Table 2 shows the thermal conductivity of polyimide resin to which various kinds of thermal conductive fillers

Table 2. Thermal conductivity of the polyimide resin with various thermal conductivity fillers mixed

Kind of filler	Shap	Mean particle size (μm)	Thermal conductivity (W/mK)
SiO_2	Spheroidal	2.0	0.36
Al_2O_3	Spheroidal	3.0	0.42
SiC	Fracture	3.2	0.54
TiO_2	Needle shape	0.27ø × 5.2L*	0.36
Graphite	Squama shape	3.0	0.56
BN	Squama shape	1.0	0.54
CNF	fibroid	150nmø × 8.0L*	1.48

Amount of filler mixing: 25vol%

: The diameter and length are described for a needle shape and fibroid filler.

are applied at the rate of 25vol%. Fixing-film sleeves with CNF showed the thermal conductivity of 1.48 W/mK, which is about 2.7 times higher than that of the conventional fixing-film sleeve with BN at 25vol% (0.54 W/mK). Therefore, we selected CNF as the thermal conductive filler. **Figure 5** shows the relation between CNF quantity and thermal conductivity of fixing-film sleeves. It is thus concluded that increase in the amount of CNF improves thermal conductivity.

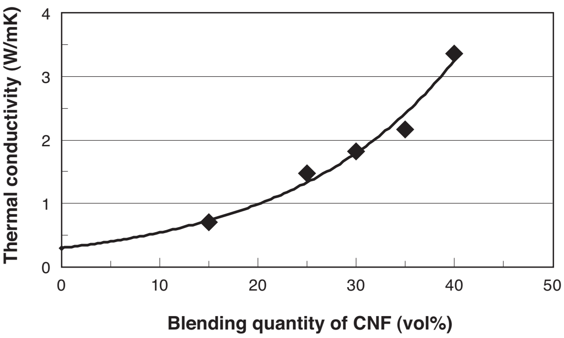

Fig. 5. Relation between blending quantity of CNF and thermal conductivity

3-3 Dispersing method of CNF

(1) Selection of dispersing method

The disperse ability of the nano materials, such as CNF, greatly influences physical properties of composite materials. To improve CNF filler's dispersibility [3], surface chemical treatment methods, such as oxidation treatment, plasma treatment and surface polymer coating are used. Physical approaches, such as adding dispersing agents (surface active agents etc.), dispersion by supersonic wave and roll milling, are also known. However, oxidation treatment and plasma treatment are difficult to be applied to products which require a large amount of CNF because batch processing is involved. Polymer coating and dispersing agents also fail to improve the mechanical strength because the remaining elements are resolved under the polyimide baking condition (around 400°C). Applying supersonic wave does not improve dispersibility, either, due to the high velocity of polyamic acid solution, the precursor of polyimide (polyimide varnish). We therefore concluded that the roll milling method is best suited to improve the dispersibility of CNF,

Table 3. Method of distributing CNF

Classification of method		example
CNF treatment	Surface chemical treatments	Oxidation treatment, plasma treatment, and ozone/UV treatment
	Surface polymer coating	Polyvinyl alcohol, Polyvinylpyrrolidone
Addition of decentralized improvement medicine	Additionof solvent	Acetone, toluene, methanol, and ethanol
	Addition of surface-active agent	Nonionic surface active agent, cationic surface active agent, and anion surface active agent
Strengthening of decentralization and mixture	Decentralization by supersonic wave	Decentralized machine by supersonic irradiation
	High share decentralization	Roll mill and rapid mixer

(2) Relation between cutting of CNF by shearing force and thermal conductivity

In the case of dispersing CNF into polymer with shearing force generated by an extruding machine, the electric conductivity is improved by enlarging the shearing force. However, it is known that when the shearing force exceeds a certain point, electric conductivity decreases [4]. This phenomenon happens because the CNF cohesion bodies get untied to form electric paths. However, after reaching a certain level, electric conductivity decreases with increasing shearing force. This is attributed to the decrease of electric paths resulting from cuts in CNF. We therefore concluded that there was a possibility that the thermal conductivity decreases because the same phenomenon happens in CNF dispersion by roll milling. **Figure 6** shows the relation between roll milling frequency and thermal conductivity. The thermal conductivity of fixing-film sleeves made of polyimide varnish increases when roll milling is conducted once, compared to when no roll milling is applied (only stirring by a propeller agitator). However, the thermal conductivity decreases when the roll milling frequency exceeds

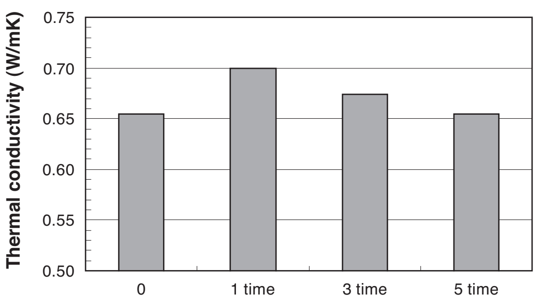

Fig. 6. Relation between processing frequency of roll milling and thermal conductivity

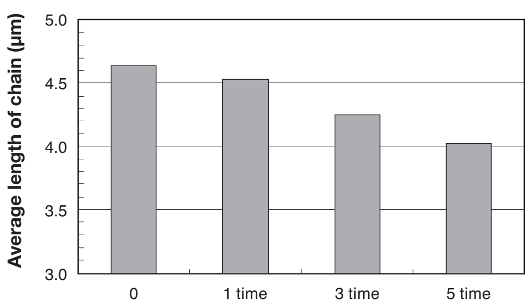

Fig. 7. Relation between processing frequency of roll milling and average length of CNF chain

three times. The thermal conductivity after five times of roll milling decreases to 0.65 W/mK. **Figure 7** shows the average chain length of CNF, which is measured by using diluted polyimide varnish mixed with CNF. When no roll milling is applied, the average chain length of CNF is 4.6 μm, while it measures 4.0 μm after five times of roll milling. Thus, we have found that CNF is cut to be short whenever roll milling is done. The thermal conductivity improves if roll milling is conducted only once. Although the average chain length is shortened, CNF dispersion effects are large enough to increase thermal conductivity. However, when roll milling is conducted more than once, thermal conductivity decreases because of the reduction of thermal conduction paths resulting from cuts in CNF.

4. Mechanical Properties of Fixing-Film Sleeves with CNF

We use a dispenser to apply polyimide varnish (**Fig. 8**). Filler with a high aspect ratio, like CNF, queues up in the circumferential direction of a fixing-film sleeve due to inner pressure received from the dispenser nozzle (**Photo 1**). **Table 4** shows the elongation and elasticity modulus, in the circumferential and axially directions, of fixing-film sleeves with 25vol % of BN or CNF mixed. The elasticity modulus, in the circumferential direction, of a fixing-film sleeve with CNF is higher than that of a sleeve with BN, whereas the anisotropy of a sleeve with CNF is stronger than that with BN. The higher the elasticity modulus is in the circumferential direction, the higher twist strength is. It is therefore concluded that a fixing-film sleeve with CNF mixed can have high twist strength due to the high elasticity modulus in the circumferential direction.

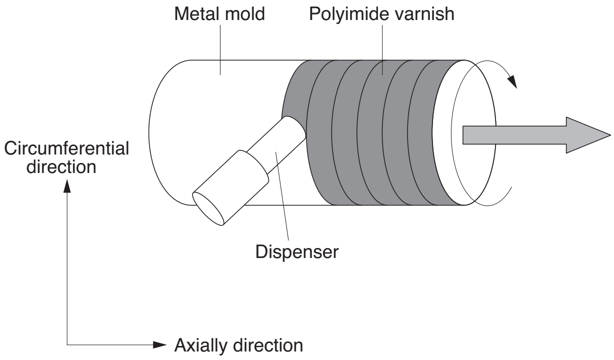

Fig. 8. Spreading method of polyimide varnish

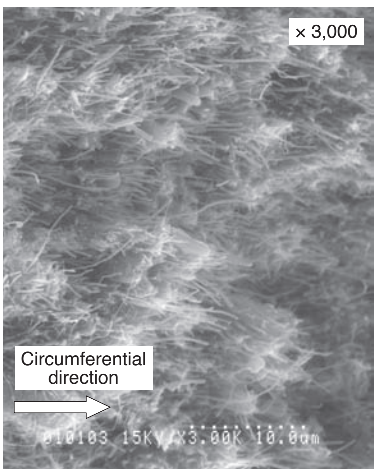

Photo 1. Cross section of fixing-film sleeve with CNF mixed

Table 4. Elongation and elasticity modulus

		BN 25vol% mixed	CNF 25vol% mixed
Elongation (%)	Circumferential direction	20	14
	Axially direction	25	26
Circumferential direction/axially direction		0.80	0.54
Elasticity modulus (kgf/mm^2)	Circumferential direction	740	818
	Axially direction	682	539
Circumferential direction/axially direction		1.09	1.52

5. Characteristic of Developed Fixing-Film Sleeves

Table 5 shows the characteristics and composition of the developed fixing-film sleeve. BN and CNF are used together for the developed fixing-film sleeve to balance thermal conductivity, twist strength, thrust strength and cost efficiency. We have succeeded in improving the thermal

Table 5. Characteristics of developed fixing-film sleeve

Item			The developed fixing-film sleeves	the conventional fixing-film sleeves
Composition	Top layer	Material	Fluorocarbon + carbon	Fluorocarbon + carbon
		Thickness (μm)	12	10
	Primer layer	Material	Fluorocarbon + bonding element + carbon	Fluorocarbon + bonding element + carbon
		Thickness (μm)	4	4
	Base layer	Material	Polyimide+ BN + CNF	Polyimide + BN
		Thickness (μm)	56	67
Thermal conductivity (W/mK)			0.70	0.54
Twist strength (cNm)			18	22
Thrust strength (N)			18.5	20.0
Fixing performance	16 paper/minutes		OK	OK
	35 paper/minutes		OK	NG

conductivity by about 30%, while decreasing the thermal capacity by about 16%, without sacrificing twist strength and thrust strength of the fixing-film sleeve. As a result, fixing efficiency of the developed fixing-film sleeve has greatly improved. The results from evaluation tests using actual machines also confirmed that the developed fixing-film sleeve is applicable to high-speed printing systems (35 papers/minute).

6. Conclusions

As mentioned above, we have succeeded in developing fixing-film sleeves that can be applied to high-speed printing systems (35 papers/minute). This resulted from great improvement in thermal conductivity, and decrease in thermal capacity by making a fixing-film sleeve thin compared with the conventional models (16 papers/minute). The developed fixing-film sleeve has been officially adopted by Canon Inc. and other companies since June 2008. We intend to promote the development of products corresponding to the market trends for faster LBPs and other demand in the future.

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Contributors (The lead author is indicated by an asterisk (*)).

S. NAKAJIMA*

- Polymer Materials Technology R&D Department,
  Electronics & Materials R&D Laboratories
  He is engaged in the development of Fixing-Film sleeves.

Y. UCHIBA

- Manufacturing Department,
  Sumitomo Electric Fine Polymer, Inc.

N. ONMORI

- Assistant Manager,
  Functional Fluororesin Products Engineering Department,
  Sumitomo Electric Fine Polymer, Inc.

Y. SUZUKI

- Factory Manager, Functional Fluororesin Products Plant,
  Sumitomo Electric Fine Polymer, Inc.

J. SUGAWARA

- Manager, Polymer Synthesis & Technology Group
  Polymer Materials Technology R&D Department,
  Electronics & Materials R&D Laboratories

A. MIZOGUCHI

- Senior Assistant General Manager,
  Polymer Materials Technology R&D Department,
  Electronics & Materials R&D Laboratories

K. KIZAWA

- General Director, Sumitomo Electric Interconnect Products (VIETNAM), Ltd.