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EPDM Rubber Rollers Adapted to Various Types of Media

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ABSTRACT: As photocopiers, printers, and other office equipment rapidly become more sophisticated and commonplace, they are reaching an increasingly globalized market. Office copying equipment is also improving in terms of its capability to produce high-quality color output. At the same time, users are increasingly expecting their equipment to work with a wider range of media such as lower-quality plain paper and coated photo paper. As a result, the pick-up and feed mechanisms in such equipment must use rubber rollers that are more durable and do not contaminate the media surface. To meet this demand , Hitachi Cable has developed new pick-up and feed rollers based on EDPM (ethylene propylene diene monomer) polymers.

Our studies have shown that coated paper and lower-quality plain paper contain more polar resins than standard Japan-made plain paper, and that these resins are closely associated with reduced coefficients of friction on the roller surfaces. We have therefore developed new materials based on polymers of EDPM—a non-polar material that has a low affinity for polar resins—and have produced EDPM compositions with optimal characteristics by thoroughly investigating how the roller characteristics are affected by such factors as the polymer molecular weight, the type and quantity of oil, the type and quantity of the filler, and the cross-linking system. As a result, we have developed two new roller materials—one for use in photocopiers with improved wear resistance that can tolerate lower-quality plain paper, and the other for use in inkjet printers, where it causes less media contamination.

〔1〕 INTRODUCTION

Remarkable improvements have been made in the performance of office equipment such as personal computers, and inkjet printers are no exception. These days, even ordinary low-cost equipment is capable of producing high-quality images comparable to conventional photographs. To complement this improved quality, there has been substantial diversification in the types of media (such as paper) provided exclusively for color printing. It is not uncommon for a single manufacturer to offer over a dozen different types of media, such as heavyweight paper and glossy photo paper. All these media have special coatings that have been applied to the printing surface to improve the ink absorbency,[1] and on the whole, they tend to reduce the coefficient of friction (μ) of pick-up and feed rollers. Another problem is that pick-up rollers can easily transfer oily particles to the surface of glossy media on contact, which results in printing defects. To solve this problem, we need pick-up rollers that can better tolerate coated paper and cause less contamination.

On the other hand, due to the globalization of the market for office copying equipment such as printers and photocopiers, this equipment often has to work with different types of plain paper stock manufactured in different countries worldwide. This paper is often of lower quality than the standard plain paper manufactured in Japan, and can easily reduce the coefficient of friction of the pick-up and feed rollers.

Hitachi Cable has already developed a wide range of rubber roller components for use not only in office equipment such as printers, photocopiers, and fax machines, but also in other types of media-handling equipment such as cash dispensing machines. These components are marketed under the “Rubber Series” trade name. In the present study, we have developed new materials for the purpose of obtaining (i) pick-up rollers that are more tolerant of lower-quality plain paper, and (ii) pick-up rollers for inkjet printers that produce less contamination and can better cope with coated paper.

Specifically, this paper describes high-performance pick-up rollers of the “Rubber E” series we developed. First, we will illustrate the mechanism that enables reducing the coefficient of friction of rollers by using media. We will then describe EDPM-based “Rubber E” pick-up and feed rollers with high μ stability that we developed based on our findings. Finally, we will provide a list of all rubber materials for paper pick-up and feed rollers that have so far been developed by Hitachi Cable.

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〔2〕 REDUCING μ BY USING NEW MEDIA

2.1 Changes in the pick-up roller μ with various types of new media

Figure 1 shows how the kinetic friction coefficient of a feed roller made from "Rubber V" (our leading product) changes after 2,000 sheets of various types of media have been fed through the printer. To obtain these results, we used the retard roller accelerated paper feed test apparatus shown in **Fig. 2**,[2] and we measured μ by using the friction coefficient measuring apparatus shown in **Fig. 3**.[2] As the results show, standard plain paper made in Japan causes less reduction of μ than coated paper and lower-quality plain paper made in other countries. The reduction of μ was particularly significant with plain paper made in country A and with non-glossy coated paper A.

Figure 4 shows the surface of a pick-up roller after it had been used to feed plain paper from country A in this experiment. This figure clearly shows that the reduction of μ was caused by a large number of needle-shaped paper particles that had stuck to the surface of the roller.

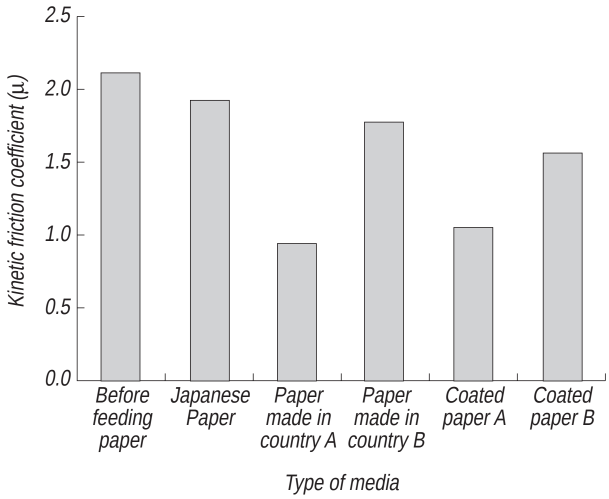


Fig. 1—Changes in roller μ with various types of media
This graph shows how the friction coefficient of a "Rubber V" roller changes after feeding 2,000 sheets of each type of media. The reduction of μ is particularly significant with plain paper made in country A and with coated paper A.

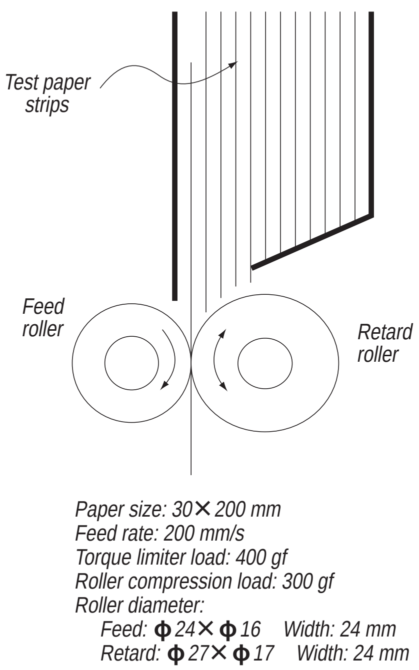


Fig. 2—Retard roller accelerated paper feed test apparatus
This test apparatus simulates the pick-up mechanism of office equipment such as photocopiers and laser printers, and allows such parameters as the feed rate and compression load to be set arbitrarily.

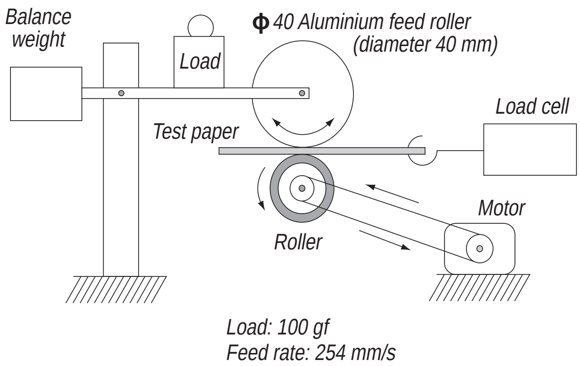


Fig. 3—Friction coefficient measuring apparatus
This apparatus can measure the coefficient of friction around the roller. The friction force is measured with a load cell and logged by using a recorder or a PC.

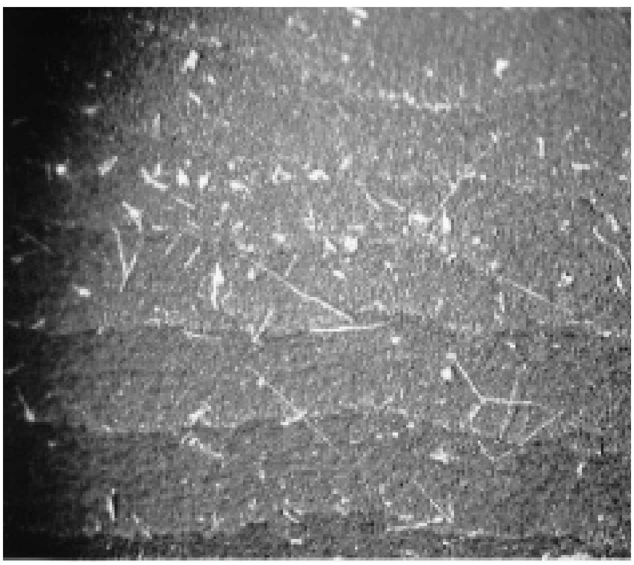
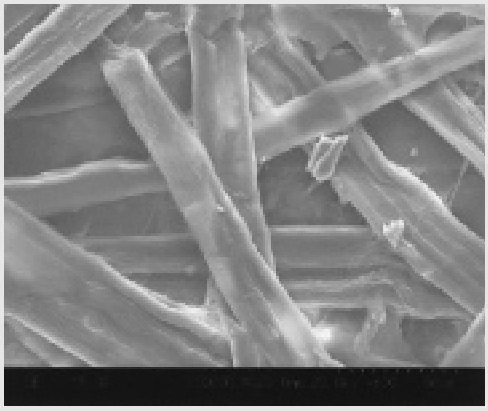


Fig. 4—Roller surface after feeding the paper made in country A
The roller surface is covered with many needle-shaped paper particles, which greatly reduce the friction coefficient.

TABLE 1 THE PROPERTIES OF PLAIN PAPER MADE IN JAPAN AND IN COUNTRY A

The paper produced in country A has thicker fibers and contains more resins.

Media	Japan made plain paper	Plain paper made in country A
Enlarged photograph	 50µm	 50µm
Extractant	Ester-based resins	Ester-based resins
Amount of extractant	0.2 wt%	0.5 wt%

2.2 The composition of various types of media

We soaked samples of plain paper made in Japan and in country A in acetone for 24 hours, and then subjected the extract to mass measurement and FT-IR identification. The results are shown in **Table 1** along with electron micrographs of the paper surfaces.

The amount of ester-based resins extracted from the plain paper made in country A was more than twice that extracted from the plain paper made in Japan. This is thought to arise from the differences in the quantity of the sizing resin added to adjust the ink penetration and the quantity of residual resins left after the pulp refinement process. As the enlarged images of the paper surfaces show, the fibers in the plain paper made in country A are thicker and more rigid, which probably means that more additives were used in the manufacturing process to strengthen the fiber bonding and increase the paper's resistance to picking.

We subjected coated paper to a similar analysis, and found that the extractant contained not only ester-based resins but also PVA (polyvinyl alcohol), which is used as a binder for coating agents.

These resins all readily dissolve in ordinary polar rubber plasticizers such as DOP (dioctyl phthalate) and DINP (dinonyl phthalate), and are known to have a strong affinity for rubber materials that contain these plasticizers.

2.3 Mechanism for the reduction of roller μ by using new media

Based on these results, the mechanism for the reduction of roller μ by using lower-quality plain paper and coated paper is thought to be as follows:

(i) The fibers in lower-quality plain paper are shorter and thicker and are thus less entangled with one another, making it more likely to release paper dust particles. Coated paper can also produce paper dust easily due to the flaking of the coating agent.

(ii) Because any paper dust that is produced contains a lot of resins that have a strong affinity for plasticizers in rubber, the needle-shaped particles do not fall off the rubber roller but instead build up in a snowball fashion, causing the roller μ to decrease substantially.

The properties of such types of media make it impossible to avoid producing paper dust during the pick-up process. We therefore developed new materials whose composition prevents paper dust particles from adhering to the roller surface.

(3) DEVELOPMENT OF A PICK-UP ROLLER FOR NEW MEDIA

3.1 Polymer selection

Because paper dust contains polar resins that have a strong affinity for polar plasticizers, we opted for a system in which a non-polar plasticizer could be applied to polymers. **Table 2** lists the solubility parameters (SP values) of various plasticizers and polymers as an indicator of their molecular polarity.[3)]

In this table, larger SP values indicate molecules with stronger polarity. The plasticizer with the weakest polarity is therefore paraffin oil. Polymers to which this can be applied include IIR, EDPM, and NR, which have similar SP values. In this study, we decided to base the new materials on EDPM, which has a balanced set of properties such as atmospheric resistance, oil-extension properties, and workability.

TABLE 2 SP VALUES OF VARIOUS MATERIALS
Larger values indicate molecules with stronger polarity, and materials with similar values have strong affinity for each other.

Material		Abbreviation	SP value
Polymers	Butyl rubber	IIR	7.8
	Ethylene-propylene rubber	EPDM	7.9
	Natural rubber	NR	8.0
	Butadiene rubber	BR	8.4
	Styrene-butadiene rubber	SBR	8.6
	Chlorinated polyethylene	CPE	9.0
	Chloroprene rubber	CR	9.2
	Acrylic rubber	ANM	9.4
	Nitrile rubber	NBR	9.6
Plasticizers, etc.	Paraffin oil	—	6~8
	Naphthene oil	—	7.5~8.5
	Aromatic oil	—	9.0~9.5
	Adipate oil	—	8.5~9.5
	Phthalate oil	—	9.5~11.0
	Polyvinyl alcohol	PVA	12.6

3.2 Development of a durable wear-resistant material for photocopiers

3.2.1 Materials investigation

Most photocopiers and laser printers have a retard roller separator mechanism (**Fig. 5**).[4] Although such a mechanism can separate paper sheets at a high speed, the rollers are subjected to large loads and must exhibit a high degree of wear resistance.

The usual way in which the friction coefficient of rubber materials is increased is by adding more plasticizer, thereby reducing their hardness. However, the addition of more additives significantly reduces the materials' wear resistance. **Figure 6** shows how the amount of plasticizer added to a standard EDPM blend affects the JIS-A hardness and the amount of wear as measured by a Williams tribometer.[5] Here, the Williams tribometer was operated at a rotation speed of 38 rpm, with a load of 3.62 kgf by using G240 sandpaper. As the graph shows, the wear resistance declines sharply when the hardness is reduced below 30 by adding more plasticizer.

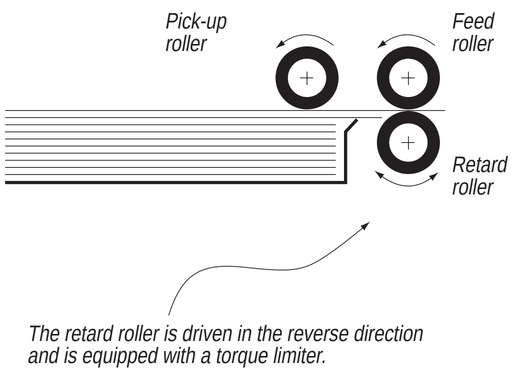


Fig. 5—Retard roller separator mechanism
Although this mechanism can separate paper sheets quickly and reliably, the rollers are easily worn out.

We therefore studied the use of polymers with high molecular weights at the limit of workability, and made a detailed investigation with the aim of optimizing various parameters such as the cross-linking system, the type and quantity of the filler, and the viscosity and quantity of plasticizer added to the material. As a result, we developed "Rubber E": HAE201-30, which combines low hardness with high μ and superior wear resistance.

As an example of how this study was carried out, **Fig. 7** shows how different vulcanization accelerators affect the relationship between μ and wear resistance for a given quantity

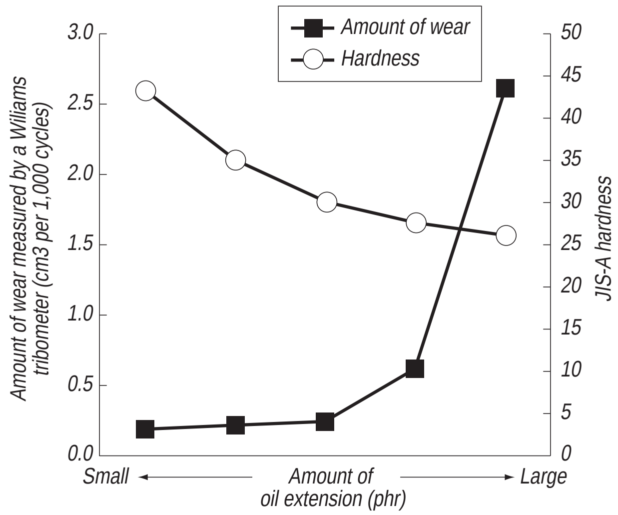


Fig. 6— Relationship between oil extension and wear resistance/hardness
As the amount of oil increJIS-A hardness, the wear resistance decreases.

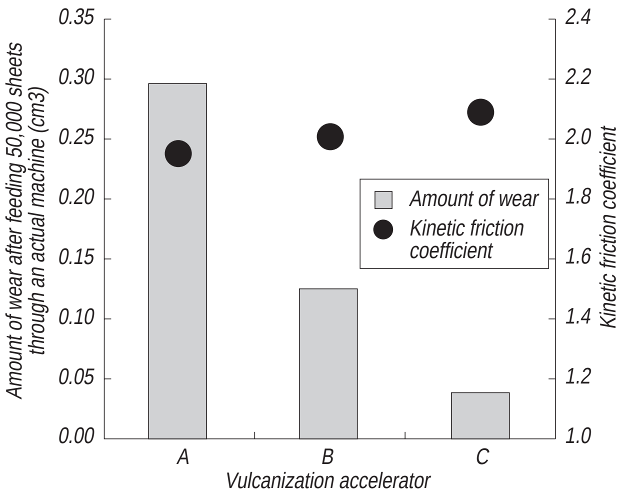


Fig. 7—Relationship between vulcanization accelerators and wear resistance
Wear resistance greatly depends on the combination of vulcanization accelerators used.

of sulfur in the vulcanizing agent. Here, the wear resistance was evaluated as a change in the volume of the roller after feeding 50,000 sheets of Japanese plain paper through an actual photocopier. Both μ and the wear resistance varied greatly depending on the vulcanization accelerator used. With vulcanization accelerator C, we achieved a high coefficient of friction as well as favorable wear resistance. We therefore used this vulcanization accelerator C in the production of HAE201-30.

3.2.2 The performance of HAE201-30 with lower-quality plain paper

Figure 8 compares rollers made of three different materials in terms of the number of sheets of lower-quality plain paper (made in country A) that the rollers can feed before it becomes impossible to do so due to the reduction of μ. These results were obtained by conducting tests with an actual photocoper. The performance of "Rubber V", which uses an ester-based plasticizer, degrades rapidly. However, HAE201-30 lasts much longer than the general-purpose product, even though both materials are based on EDPM.

3.3 Development of a non-contaminating material for inkjet printers

3.3.1 Materials investigation

These days, most inkjet printers use a separator pad pick-up mechanism as shown in **Fig. 9**. This mechanism allows the overall pick-up system to be made at low cost, and can separate various types of paper stably up to a certain speed.

Besides the ability to withstand the feeding of a large number of sheets, a particularly important requirement for pick-up rollers for inkjet printers is that they cause minimal contamination of the printing surface.

In the pick-up mechanism shown in **Fig. 9**, the roller comes into direct contact with the printing surface of the media. Depending on the composition of the roller material, oily constituents can sometimes be transferred to (i.e., contaminate) the printing surface, giving rise to printing defects. Now that inkjet control techniques have been improved to the point where inkjet printers can produce images comparable in quality to conventional photographic prints, there is a growing demand for rollers that do not cause media contamination and can tolerate coated paper for color printing.

Therefore, in addition to "Rubber E": HAE201-30, we have also developed a new EDPM material with superior non-contaminating properties specifically for use in inkjet printer pick-up rollers.

Figure 10 shows enlarged photos of the surface of a sheet of paper printed with a solid block of a single color. It can clearly be seen that the ink dots have a smaller diameter than usual in the parts that came into contact with the roller, and as a result, these parts appear to have a different color. Inkjet printers mainly use water-based ink, so if a hydrophobic substance (mainly the plasticizer in the rubber) is transferred to parts that come into contact with the roller, the wettability of the paper by the ink is reduced.

In the previous section, we showed that rollers can be made more tolerant of lower-quality plain paper by using non-polar paraffin oil as the plasticizer. However, a non-polar plasticizer is more hydrophobic than a polar plasticizer. As a result, the material, HAE201-30, we developed for use with lower-quality plain paper is not necessarily ideal for use with coated paper of this sort due to the likelihood of contamination.

Factors that might influence the contamination properties include (i) the affinity of ink for the plasticizer transferred from the roller, (ii) the amount of plasticizer transferred to the media surface, and (iii) the diffusion of the transferred plasticizer into the media. Because these factors can vary depending on the molecular weight, molecular structure, and composition of the plasticizers (even if they have similar SP values), we undertook an additional investigation of various types of plasticizers.

The μ stability, wear resistance properties, and contamination properties exhibit uniform tendencies with respect to the viscosity and degree of refinement of the plasticizer, and we found that there are optical compositions for each type of plasticizer. However, there is no single composition that satisfies all of these conditions (You never specified the conditions, so this may be unclear. I suggest "...composition that provides μ stability, enables high wear resistance, and prevents contamination), and we therefore

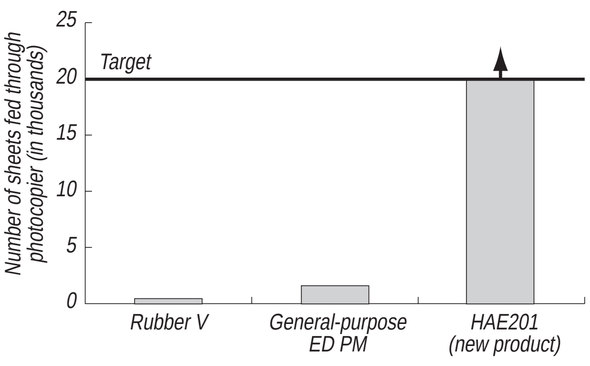


Fig. 8—Roller lifetimes when the rollers are used to feed lower-quality plain paper
HAE201-30 roller lasts much longer than the general-purpose EDPM roller, and can feed over 20,000 sheets.

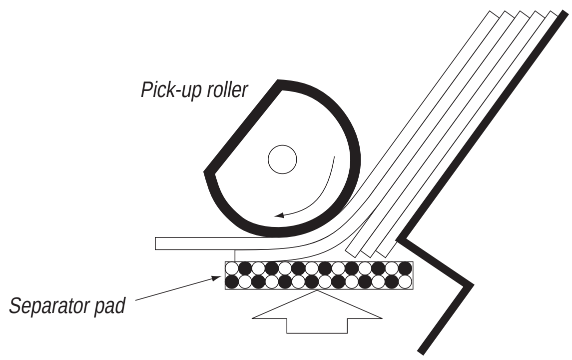


Fig. 9—Separator-pad-type separator mechanism
This is the separator mechanism currently used in most inkjet printers.

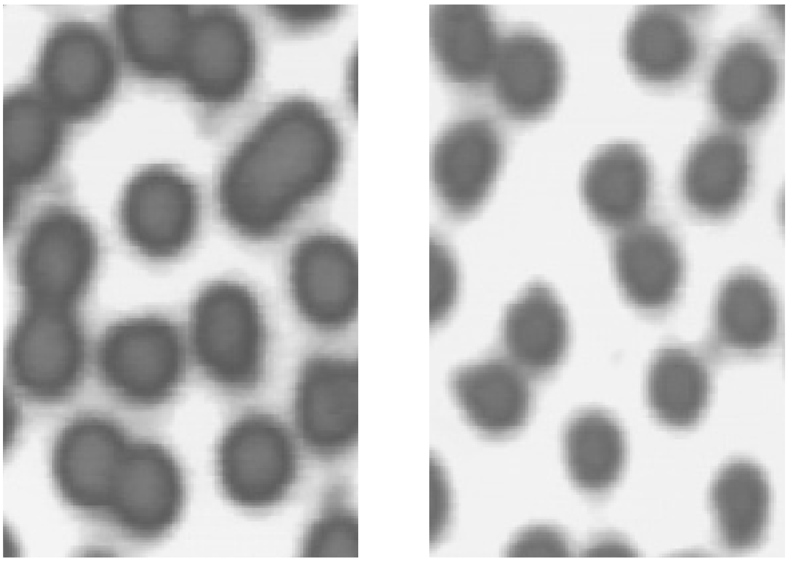


Fig. 10—Enlarged photos of printed surface
The ink drop diameter was smaller in parts contaminated by the roller, resulting in printing defects.

struck a balance by blending multiple types of plasticizer. As a result, we arrived at "Rubber E": HAE303-40, which is a pick-up roller for inkjet printers that satisfies all of these conditions to a high degree.

3.3.2 The characteristics of HAE303-40

Figure 11 shows the results of printing a solid block of a single color in the region that comes into contact with the roller. These results were obtained by using a general-purpose EDPM pick-up roller and an HAE303-40 pick-up roller in a real inkjet printer. With the general-purpose EDPM roller, there is a visible printing defect caused by the transfer of plasticiser from the roller to the surface of the paper, whereas with HAE303-40, there are hardly any printing defects of this sort.

Figure 12 shows how the friction coefficients of different retard rollers change after feeding 2,000 sheets of coated paper A. These results were obtained using the retard roller accelerated paper feed test apparatus shown in **Fig. 2**. As can be seen from the figure, the friction coefficient of HAE303-40 decreased less than that of the other materials, demonstrating that this material can better handle coated paper.

(4) MATERIALS FOR RUBBER ROLLERS

Table 3 lists the rubber materials that Hitachi Cable has developed so far to meet the various requirements for rubber materials for office equipment.[6] It is essential that the rubber material be selected upon careful examination of the environment and conditions under which it will be used.

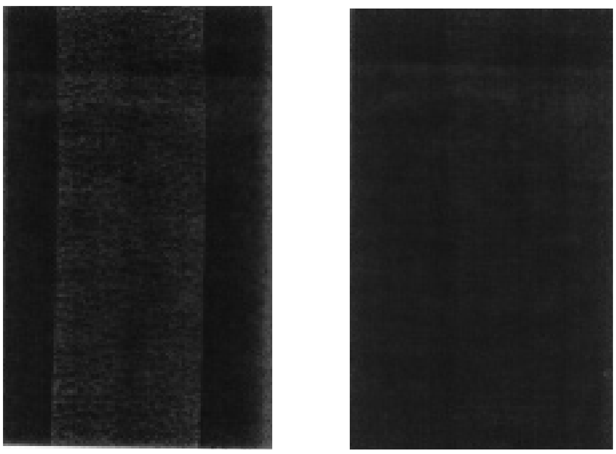


Fig. 11—Results of printing in the pick-up roller contact region
No printing defects occur when using a feed roller made of HAE303-40.

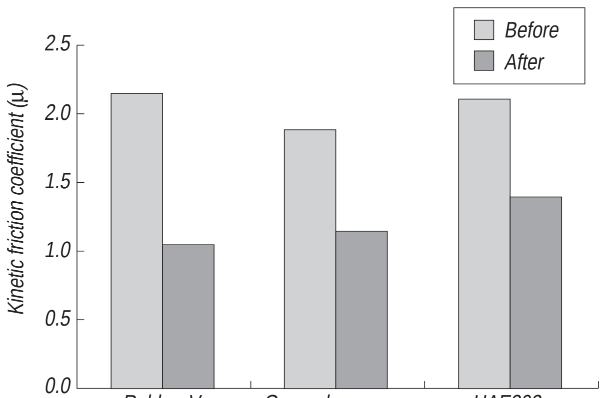


Fig. 12—Change of μ after feeding 2,000 sheets of coated paper A
HAE303-40 is less susceptible to the reduction of μ when using coated paper.

TABLE 3 THE PROPERTIES OF RUBBER MATERIALS DEVELOPED BY HITACHI CABLE FOR USE IN OFFICE EQUIPMENT
It is important to select the material carefully for each application and set of objectives.

Item	Hitachi cable tradename	Wear resistance	Friction coefficient	Resistance to new media	Contamination properties	Ozone resistance	Ultraviolet resistance	Hardness	Benefits and drawbacks	Applications
EPDM	Rubber E	◎	◎	◎	○	◎	◎	30~50	High μ, good wear resistance and μ stability.	Pick-up, separation, feed
CPE	Rubber V	◎	◎	△	◎	◎	◎	25~70	High μ, good wear resistance and contamination properties.	Pick-up, separation, feed
Urethane	Rubber Rubber foam	◎	△	◎	◎	◎	△	30~80	Excellent wear resistance at high hardness. At lower hardness it is susceptible to hydrolysis, which reduces the coefficient of friction. The μ stability is improved by foaming.	Separation, feed separation
NR	Rubber N	◎	◎	◎	○	×	△	30~80	Good wear resistance and μ stability. Unless tube expansion is done, the ozone resistance is also acceptable.	Pick-up, separation, feed
CR	Rubber C	○	△	×	◎	△	△	30~80	Has a good balance of expansion characteristics, but lacks μ stability.	Feed
SBR	Rubber B	○	○	○	△	×	△	30~80	Similar to NR, but more resilient to wear and friction heating.	Separation
NBR	Rubber A Rubber Z	○	△	×	◎	×	△	30~80 70~90	Suitable for carbonless paper applications. A super wear resistant grade is also available. Unless tube expansion is done, the ozone resistance is also acceptable.	Pick-up, separation, feed
Polynolbonene	Rubber X	◎	◎	△	△	×	×	20~40	High μ at low hardness, and good wear resistance.	Pick-up
Silicone	Rubber Q	○	○	△	×	◎	○	30~80	Good heat resistance, but expensive and low μ.	Platen
Rubber/resin composites	Rubber G	○	○	○	△	×	△	50	Exhibits the complementary properties of having a high μ for paper and a low μ for glass surfaces.	Reading

(5) CONCLUSION

We developed pick-up rollers adapted for new media such as coated paper for color printing and lower-quality plain paper. In the development process, we have reached the following conclusions:

(1) Coated paper and lower-quality plain paper can dramatically reduce the friction coefficient of rollers (especially those containing polar plasticizers) because they contain large amounts of polar resins that cause paper dust particles to adhere to the roller surface.

(2) To prevent the adhesion of paper particles, we have developed “Rubber E”: HAE201-30. This material is made by adding optimal amounts of oil and filler to an EDPM-based polymer with a high molecular weight and an optimized cross-linking system, and can be used to produce pick-up rollers that can better tolerate lower-quality plain paper than conventional rollers do.

(3) We have also developed “Rubber E”: HAE303-40 by blending in a combination of different types of non-polar plasticizers. This material can be used to produce pick-up rollers for inkjet printers that do not suffer from printing defects in parts where the roller comes into contact with the printing surface, and that can better tolerate coated paper.

The performance of pick-up and feed rollers strongly depends not only on the material from which they are made, but also on their shape and surface finish. At Hitachi Cable, we take all these factors into account when developing new rollers. In the future, we will continue to take advantage of our overall technical expertise as a roller manufacturer and will maintain our leading position in this field by developing new products.

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