Abridged version

KAWASAKI STEEL TECHNICAL REPORT

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of the Technical Research Division

Dependence of Xerographical Developability Ferrite Carrier Properties

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Synopsis :

The dependence of xerographical developability on carrier properties was studied using commercial plan paper copies. Recently, the steel beads carrier has been replaced by a ferrite carrier as a xerographic developer, but the developability of the latter has not yet been clarified. Measurements of image density, print contrast and the residual toner mass were made to elucidate the relationship between characteristics of the ferrite carrier and its developability. The image density increased, as the dielectric constant of the developer increased and the diameter of carrier beads decreased. The contrast of the print became flatter with an increase in the carrier beads' diameter. The residual toner mass increased as the toner charge distribution broadened. The surface condition of carrier beads effected the toner charge distribution, and a minimum residual toner mass was attained when the sizes of the carrier surface grains were similar to those of toner particles.

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Dependence of Xerographical Developability of Ferrite Carrier Properties*




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The dependence of xerographical developability on carrier properties was studied using commercial plain paper copiers. Recently, the steel beads carrier has been replaced by a ferrite carrier as a xerographic developer, but the developability of the latter has not yet been clarified. Measurements of image density, print contrast and the residual toner mass were made to elucidate the relationship between characteristics of the ferrite carrier and its developability. The image density increased, as the dielectric constant of the developer increased and the diameter of carrier beads decreased. The contrast of the print became flatter with an increase in the carrier beads' diameter. The residual toner mass increased as the toner charge distribution broadened. The surface condition of carrier beads affected the toner charge distribution, and a minimum residual toner mass was attained when the sizes of the carrier surface grains were similar to those of toner particles.

1 Introduction

Xerography is one of the most remarkable inventions of this century. It makes duplication of documents easy, and extends the range of communication. The most popular application of xerography is in a plain paper copier. It works through a combination of the photoconductor drum and the magnetic developer carrier. Several investigations on the relationship between characteristics of the development system and xerographic developability have been reported in the literature[1~13], but there is little quantitative data concerning the relationship between properties of the developer carrier and its developability.

Kawasaki Steel produced a ferrite carrier for the xerographic developer from iron oxide recovered from pickling acid in the steelworks. In the present paper, the dependence of xerographic developability on the properties of the ferrite carrier which was clarified through its production will be reported.

2 The Plain Paper Copier and the Ferrite Carrier

2.1 Mechanism of the Plain Paper Copier

The process of the plain paper copier is illustrated schematically in **Fig. 1**. This process illustrates an excellent application of static electricity, and operates on the surface of the photoconductor drum, that is, an aluminium roller coated by photoconductible materials (e.g. selenium, cadmium sulfide or amorphous silicon). It involves the following six steps:

(1) Charge: A corona discharge uniformly charges the surface of the photoconductor drum in darkness.
(2) Expose: The photoconductor drum is exposed to light reflected from the original document. The areas exposed to the light are become conductive

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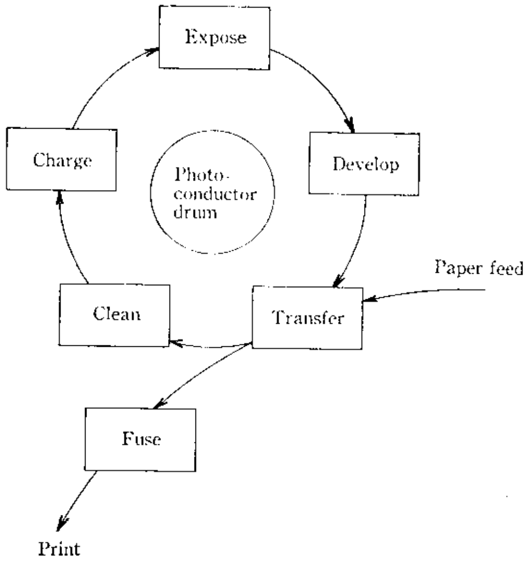

Fig. 1 Schema of the six steps in the xerographic process

and discharge, and remaining charge forms a latent image—a charge pattern corresponding to the original image on the photoconductor.

(3) Develop: The latent image on the photoconductor drum is developed into a real image by the toner. The toner consists of pigmented polymer particles charged oppositely to that on the photoconductor drum.

(4) Transfer: The developed toner on the photoconductor drum is transferred to paper by corona discharge giving the paper an opposite charge to that of the toner particles.

(5) Fuse: The toner image is fixed to the paper by heat or solvent.

(6) Clean: Excess toner and the remaining charge are removed from the photoconductor drum.

The most important step of this process is "develop". It affects image density of the prints, the tone reproduction property of the copier and the amount of residual toner mass—excess toner that is cleaned from the surface of the photoconductor drum. Xerographic developers in the plain paper copier development system are classified according to how they transport the toner particles, as shown in **Fig. 2**. The magnetic brush developer has been most widely applied recently because it is able to develop at a high rate and avoid "edge effect"—enhancement of the edges of solid areas by an electric field. In this method, magnetic developer powder is attracted to a magnet and forms a magnetic brush, as shown in **Fig. 3**. The magnetic brush sweeps the surface of the photoconductor drum and develops the latent image. Figure 3 illustrates the magnetic brush development system. This system uses a two component developer which contains the toner (pigmented polymer particle, around 10 μm in diameter) and the carrier (soft magnetic material beads, around 100 μm in diameter). The developer is mixed uniformly by an agitator roll and charged by friction in a developer pool. As a result, the toner particles electrostatically adhere to the carrier beads. Then the carrier beads are carried into the development zone by a combination of frictional and magnetic forces exerted by a rotating developer sleeve and stationary magnets. The toner particles are transferred from the carrier beads to the latent image in the development zone when the magnetic brush sweeps the surface of the photoconductor drum. The carrier returns to the developer pool and resupply with explended toner.

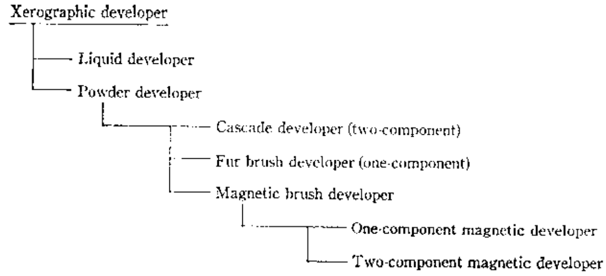

Fig. 2 Variety of the xerographic developer

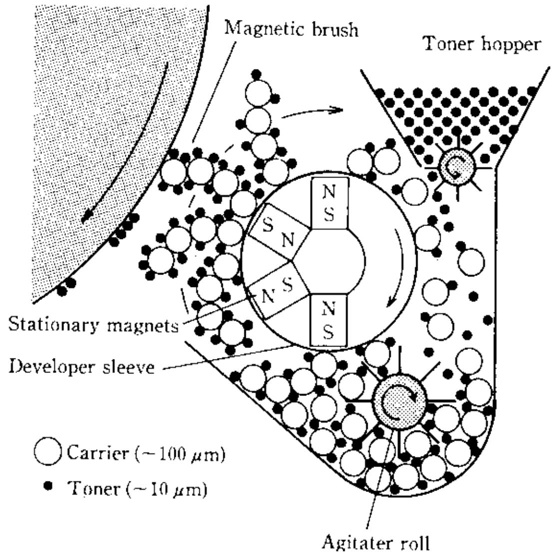

Fig. 3 Schematic of the magnetic brush developer

Principal functions of the carrier are as follows:

(1) Frictional electrostatic charge generation: An electrostatic charge is generated uniformly by mixing with the toner.

(2) Transportation: Transport of the electrostatically adhered toner to the development zone.

(3) Development: Formation of the magnetic brush in the development zone and development of the latent image by sweeping the surface of the photoconductor drum.

Table 1 Requirements for the characteristics of ferrite carrier

Magnetic properties	Saturated magnetization Coercive force Permeability
Electric properties	Specific resistivity Specific charge Dielectric constant
Powder characteristics	Mean diameter Diameter distribution Apparent density Surface roughness Flow rate
Persistency	Environmental endurance Copy volume of endurance

(4) Scavenging: Taking away the excess toner from the surface of the photoconductor drum.

The carrier is required to perform the above functions consistently for tens of thousands of copies and it must have the characteristics shown in **Table 1** in order to fulfill these requirements.

2.2 The Merits of the Ferrite Carrier

Steel beads were applied as a xerographic developer carrier in plain paper copiers but recently they have been replaced by the ferrite carrier because of its advantages, which are as follows:

(1) It has high durability since it is made from uniform stable oxide.

(2) Its characteristics can be widely controlled according to its composition or sintering condition.

(3) Its density is about 2/3 that of steel beads.

Thus, the development system of a plain paper copier, which using ferrite carrier, can be designed smaller, requires less frequent maintenance, and has a higher rate of copying than one using steel beads.

3 Experimental Procedure

A specimen was prepared by the process shown in **Fig. 4**. Raw materials of ferrite were mixed and milled into slurry by a wet mill with steel beads. The slurry was spherically granulated with spray drier, and then it was sintered in an electric furnace. Sintered cakes, made of spheres, were separated into independent spheres and classified into mean diameters of 54, 68, 81, 96 and 115 μm by sieve openings of 46, 62, 74, 88, 105 and 125 μm, respectively. A typical example of a secondary electron image of the ferrite carrier is shown in **Photo 1**.

Dielectric constants of the developer and the carrier were calculated from the electric capacitance of the twin electrodes filled with the specimen. The specific charge

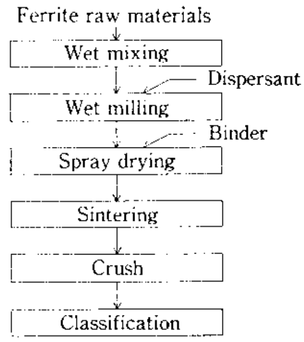

Fig. 4 Manufacturing process of ferrite carrier

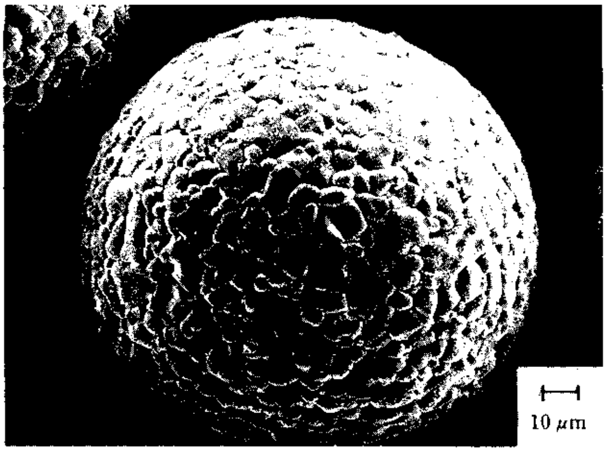

Photo 1 Ferrite carrier

of the toner was measured by blow-off method, and quality of the copy was evaluated by measuring the reflective density of the test chart copy image. Commercial plain paper copiers were used in this experiment. The specimen applied in these development systems was premixed with 4 wt.% toner. Gray scales were employed as the test charts in the measurement of image density and tone reproducibility. Residual toner mass was estimated by weighing the residual toner after making 1000 copies of a sheet of typical printing matter.

4 Result and Discussion

4.1 Image Density

Image density (ID)—a reflective density of the black area on the copy—is defined in Eq. (1).

$$\mathrm{ID} = -\log R \quad \cdots\cdots (1)$$

where R: reflectivity

ID was calculated from Eq. (2) in the coverage model[14] with paper reflectivity, toner reflectivity, and adhered toner mass onto a unit area of paper. It increases with an increase in the mass of adhered toner and saturates at the density of R_t.

$$\mathrm{ID} = -\log\{R_p \exp(-kM) + R_t[1 - \exp(-kM)]\} \quad \cdots\cdots (2)$$

where R_p: reflectivity of the paper
R_t: reflectivity of the toner
M: mass of adhered toner onto a unit area (kg/m²)
k: constant

The photoconductor drum should be fully covered with the adhered toner in order to obtain a bright copy, but copy cost is affected by excess toner. Hence, the carrier is required to develop the toner properly throughout its operating life.

The mass of the adhered toner is expressed in Eq. (3) using Shein's model.[3~5,11,12]

$$M_d = \frac{\pi}{2} \times \frac{V_0}{L} \times \frac{\varepsilon_0 K_E}{Q/m} \times \left|\frac{V_r}{V_p}\right| \quad \cdots\cdots (3)$$

where M_d: mass of adhered toner onto a unit area (kg/m²)
V_0: initial potential of the photoconductor drum (V)
L: gap of the development area (m)
ε_0: dielectric constant under vacuum (8.854×10^{-12} F/m)
Q/m: ratio of the toner charge and mass (C/kg)
K_E: effective dielectric constant of the developer
V_r: velocity of the development roller (m/s)
V_p: velocity of the photoconductor drum (m/s)

In this equation, M_d is determined by an electric field in the development area and a ratio of the velocities of the developer roller and the photoconductor drum. Consequently, it can be seen that initial high potential of the photoconductor drum, narrow development area gap, high dielectric constant of the developer, low charge toner, and high ratio of velocity in the developer roller and the photoconductor drum bring about a high image density. The dielectric constant of the developer is influenced by that of the carrier. Relationship between the dielectric constant of the developer and the image density is illustrated in **Fig. 5**. Such developers were prepared from a carrier of 80 μm in diameter. The image density increased with an increase of the dielectric constant of the developer, and if the dielectric constant of the developer exceed 4.5, the image density above 1.4 will be obtained. The results of Eqs. (2) and (3) are shown as a curve in Fig. 5. Experimental results agreed approximately with this.

Shein's model neglects factors of the developer powder supply rate, except for the velocity of the development roller and the photoconductor drum. But there are more relevant factors, e.g., developer density, magnetic field in the development area, and flow rate of the developer. Matsuura reported[15] that the density of the developer was affected by the product of saturated magnetization and diameter of the carrier. **Figure 6** shows that the image density increases with a decrease of the

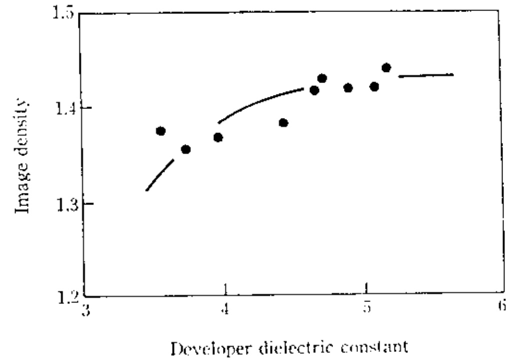

Fig. 5 Relationship between developer dielectric constant and image density

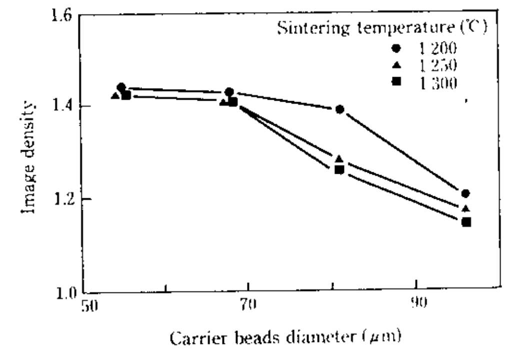

Fig. 6 Relationship between carrier beads diameter and image density for different sintering temperature

carrier diameter, and the image density above 1.4 was obtained when the carrier diameter was under 68 μm.

These experiments proved that the image density of the plain paper copier can be controlled by the dielectric constant and the diameter of the carrier.

4.2 Tone Reproduction

Tone reproducibility of the plain paper copier is usually estimated by the relationship between the density of the original and its copy, and called a tone reproduction curve. **Figure 7** presents three typical tone reproduction curves of commercial plain paper copiers. The gradient of a tone reproduction curve indicates the contrast of the copier, and is called gamma. A plain paper copier requires a high gamma value in the tone reproduction curve, as in machine A in Fig. 7, in order to clearly copy documents such as those written in pencil. On the other hand, a low gamma value is rather desirable, as in machine C, for a picture or a photograph. Since these requirements are not compatible with each other, a plain paper copier is designed such that the conflicting requirements are balanced.

The tone reproduction curve of a plain paper copier is influenced by exposure intensity, toner content in the

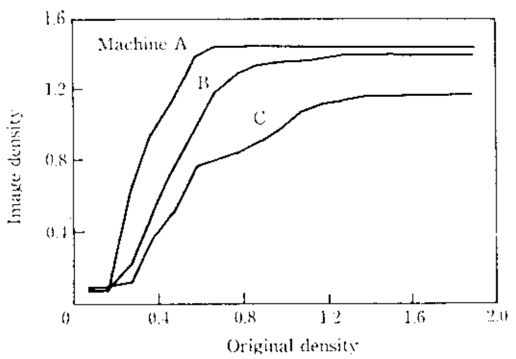

Fig. 7 Tone reproduction curves—relationship between density on original and image—as example of commercial plain paper copier

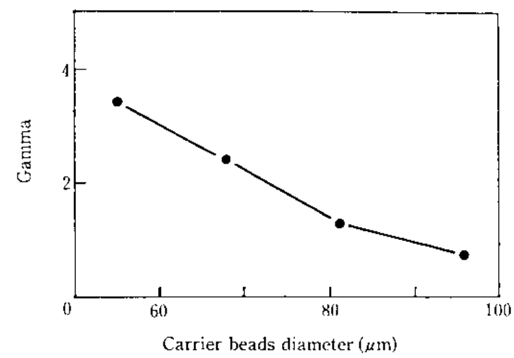

Fig. 9 Relationship between gamma, tangential inclination of the tone reproduction curve and carrier beads diameter

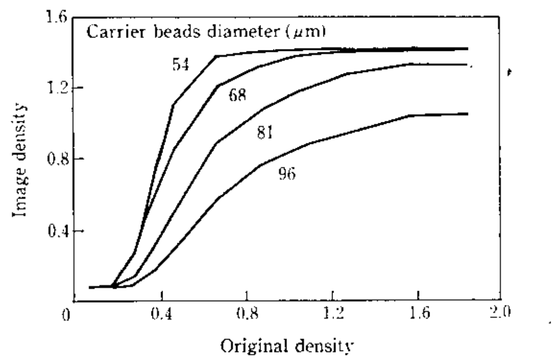

Fig. 8 Tone reproduction curves for different diameter of carrier beads

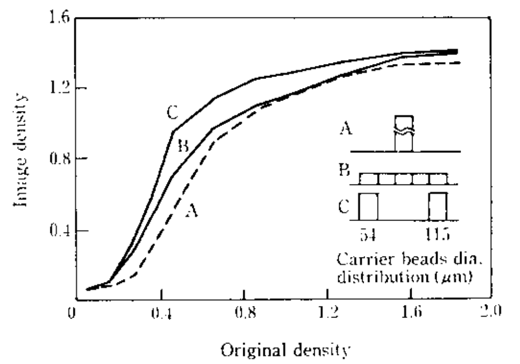

Fig. 10 Change in the tone reproduction curve for the difference of carrier beads diameter distribution

developer, and the photoconductor drum bias potential. It has been reported[16] that gamma increases with an increase in intensity of the exposure or the content of the toner, or else with a decrease in a bias potential of the photoconductor drum. To the contrary, there was very little data confirming such an effect of carrier characteristics on the tone reproduction property of a plain paper copier. A detailed experimental study of it is needed.

The influence of the carrier diameter on the tone reproduction curve is shown in **Fig. 8**. The value of gamma calculated from the curves in Fig. 8 are plotted as a function of the carrier diameter in **Fig. 9**. The gamma decreases as the carrier diameter increases, as shown in Fig. 9. This fact is probably due to a variation of developer density or specific surface area with the changing carrier diameter.

A distribution of the carrier diameter has a more complex effect on the tone reproduction property of a plain paper copier. **Figure 10** shows a change in the tone reproduction curve with the distribution of the carrier diameter at the same average diameter. The contrast in low density areas increases as the amount of small diameter carrier increases.

These experiments clarify that the tone reproduction property of a plain paper copier is governed by the carrier diameter and its distribution. The gamma is controlled in a range from 1.5 to 3.5 by a change of the carrier diameter from 54 μm to 81 μm without decreasing the image density.

4.3 Residual Toner

Toner particles which remain on the surface of the photoconductor drum after the transfer step are called residual toner. They are removed in the cleaning step and are accumulated in the waste toner bottle. They must be decreased for a cost reduction of copies. According to Tobita et al.[17,18], the coefficient of the toner transportation depends on the specific charge of the toner. But no relation was found between the residual toner mass and the average specific charge of the toner in these experiments, since, among all characteristics of the carrier, the behavior of toner particles on the surface of the photoconductor drum is affected only by the charge on it. It must result from some difference in the charge condition between developers which have different residual toner masses.

Therefore the charge on each toner particle was

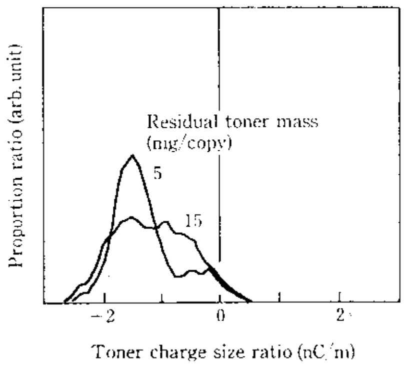

Fig. 11 Change in toner charge distribution for the different residual toner mass of developer

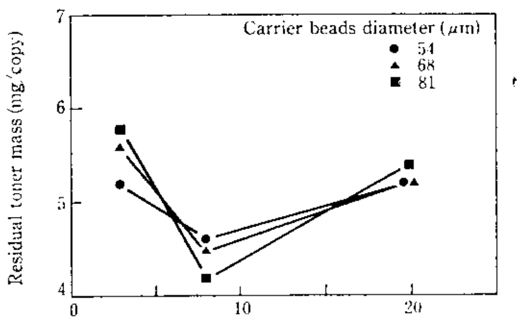

Fig. 12 Relationship between carrier surface crystal grain size and the residual toner mass for different diameter of carrier beads

measured by the improved blow-off method. **Figure 11** shows the change in the toner charge distribution for two developers which have a different residual toner mass. It revealed that the residual toner mass increased when the toner charge distribution was broadened. Similar results were reported[19,20] on deteriorated toner.

The distribution of the toner charge depend on diverse conditions on the surface of the carrier. Among these conditions, the grain size of the surface crystal of the carrier can be easily controlled by processing parameters. **Figure 12** shows the relationship between the surface grain size of the carrier and the mass of residual toner for three different diameters of the carrier beads. The mass of residual toner was varied with the surface grain size, and minimum mass was obtained when the size of surface grains were similar to those of the toner particles. It was probably related to the correlation of dielectric properties of grain boundaries to the charge generation on contact with the carrier beads and the toner particles.

5 Conclusions

The following conclusions were obtained from the experiments in order to clarify the dependence of xerographical developability on ferrite carrier properties.

(1) The image density increased with an increase of the dielectric constant of the developer and a decrease of the carrier beads' diameter. Provided the dielectric constant of the developer was over 4.5 or the carrier beads' diameter was under 68 μm, an image density above 1.4 was obtained.

(2) The contrast of the print changed according to the carrier beads' diameter. The print contrast index, gamma, varied from 1.5 to 3.5 when the diameter of the carrier beads was changed from 54 μm to 81 μm, retaining an image density of over 1.4.

(3) The print contrast in low density areas became clear as the distribution of the carrier head diameter was broadened.

(4) The mass of residual toner was dependent on the carrier beads' surface crystal grain size. The minimum mass of residual toner obtained was 4 mg for a copy when the sizes of the surface crystal grains of the carrier bead were similar to those of the toner particles.

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