Development of Developing Roller for LED Printer
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Abstract
A developing roller has a large influence on the printing quality of non-magnetic one component contact developing type LED printers by means of contact developing type with non-magnetic, carrierless toner. We developed a new developing roller by mixing electronic conductive spherical silicon powder with an electrical insulating dimethyl silicon base, molding this mixture by curing. Compared with the conventional silicon developing rollers, this roller has continuous printing durability and manufacturing stability. The roller also has superb silicon features, which are a high level of charging with toner, environmental resistance and high rubber elasticity.

1. Introduction
Recently a non-magnetic one component contact developing systems are frequently used for the development system of electrophotographic printers, where speed and resolution performance are constantly advancing. Since a sufficient electric field strength for development can be obtained with a small potential difference, a small particle sized toner can be used for this type of development method, and an electrostatic charge pattern of a latent image is accurately developed at high resolution.

The developing roller has a major influence on the print quality of non-magnetic one component contact developing type LED printers. With regard to this fact, this paper describes the development of a new developing roller essentially made from silicon1 which has various excellent characteristics.

2. Basic concept of developing roller development
2.1 Conditions required for developing roller
A developing roller requires the following characteristics to satisfy basic functions.
1. Electrical resistance (hereafter resistance) is uniform for both longitudinal direction and circumferential direction of the developing roller.
2. Surface roughness is uniform and uniform surface roughness can be maintained during continuous printing.
3. Resistance is not changed very much by environmental changes.
4. Chemical reaction does not occur with drum, blade and other components which contact the roller.

2.2 Basic composition and concept of materials
The basic composition of the developing roller that we developed this time is electrical insulating dimethyl silicon, which contains fumed silica as the reinforcing agent (hereafter called base silicon), and an electronic conducting dimethyl silicon powder (spherical particulates, hereafter called silicon powder) using carbon filler, which are mixed, pressurized and vulcanized by peroxide for molding.

1. Resistance manufacturing stability
As Figure 1 shows, the conductive mechanism tend to cause coagulation during mixing and molding because the particle size of the electronic conducting carbon filler is very small, to the order of milli μm. Since the dispersion of carbon filler constantly changes, it is extremely difficult to stabilize resistance. With the material composition of our current development, on the other hand, silicon powder has larger particle sized electronic conductive particulates, to the order of μm. Therefore, the cohesive force among particulates is dramatically smaller, and since the particulate dispersion status is stable, stable resistance is implemented.

2. Continuous stability of surface roughness
Surface roughness is an important factor to generate a uniform toner layer thickness. Generally a roller surface is finished to a specified roughness by grinding. However, as the number of printing times increases, the surface gradually wears out and surface roughness decreases. This generates a thin toner layer thickness, which decreases the printing density.

With the material composition of the new development, on the other hand, silicon powder keeps appearing on the surface as the roller surface wears, which maintains a constant surface roughness.

3. Moisture resistance and chemical reaction stability
Since silicon has low hydrophilic properties, and because the conducting mechanism is based on electronic conduction, the roller resistance does not change much under a high temperature / high humidity or low temperature / low humidity environment. Chemical reaction with the image drum, which contacts the roller, is also minimal.

Figure 1: Concept of conductive mechanism
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3. Experiment result and examination

We examined different compounding ratios between silicon powder and base silicon, in order to understand the most appropriate compounding ratio from the point of view of resistance stability and continuous stability of surface roughness. The silicon powder used here is spherical, with the average particle diameter 10 µm. Molding conditions include a 200˚C temperature, 30 kg f/cm² pressure and a 12 minute retention time.

3.1 Manufacturing stability of resistance

Figure 2 shows the volume resistivity of the roller vs. compounding ratio (weight of silicon powder / weight of silicon powder + weight of base silicon). As the compounding ratio of silicon powder increases, resistivity decreases, as does the dispersion of resistivity. When the compounding ratio of conductive silicon powder is approximately 20%, resistivity is closest to the insulation state, with almost no contact among powder particulates, and the dispersion of resistivity is also high. As the compounding ratio increases, resistivity suddenly drops when the ratio becomes 35 ~ 50%. When the ratio further increases, resistivity gradually decreases and becomes stable as dispersion decreases. This is because the powder particulates exist more closely to another and contact probability increases, which decreases resistivity and the dispersion of resistivity.

Photo 1 (a) shows cubic filling models of silicon powder, where the radius of a powder particulate is r, and density is p. In this case, 8 powder particulates can be in a cube where one side is 4r. Therefore the weight of powder wp is

\[ w_p = 8 \times (4 \pi \cdot r^{3/2}) \times p \]

When density is the same, weight w of a cube where one side is 4r is

\[ w = 64 r^3 \times p \]

this means that powder compound ratio (weight - ratio) h is given by

\[ h = w_p / w = \pi / 6 = 0.52 \]

Now let us think about the case of the closest filling cubic model, shown in Photo 1 (b), where filling density is the highest. In this case, a unit is a cube where the length of a side is the distance between centers of powder particulates, and weight is given by

\[ w = \left\{ 4r / \sqrt{2} \right\}^3 \times p \]

Since 4 powder particulates can be in a cube, h is given by

\[ h = w_p / w = \left\{ 4\pi r / 3 \times 4 \right\} / \left\{ 4r / \sqrt{2} \right\}^3 = 0.73 \]

This means that a maximum of 73% of silicon powder can be filled when the particle size is the same. Actually, filling density is not exactly like this, since there is dispersion in particle sizes, but filling density is still close to this value. When the powder compound ratio is 50 ~ 60%, the resistance becomes stable. If the compounding ratio is higher than this, millabel base silicon cannot be bonded and cannot be processed into a sheet, which makes the manufacturing of a roller impossible.

3.2 Continuous stability of surface roughness

We created a developing roller with compounding ratio h = 0.52 from a resistance manufacturing stability point of view, and conducted continuous printing testing using an Okidata printer under the following conditions: 8 ppm printing speed, a 0.25 mm contact between drum and developing roller, and a 0.5 mm contact between developing roller and toner supply.

Photo 2 shows the roller surface in the initial state, and after printing 5000 sheets (5k sheets), 10k sheets and 20k sheets. Abrasion does not progress very much up to 1k sheets, but does gradually progress from 5k sheets, where silicon powder begins to appear on the surface. When 10k sheets or more are printed, silicon powder is clearly seen on the surface, and this silicon powder on the surface generates surface roughness.
Figure 3 shows surface roughness $R_z$ on the roller surface in the initial state and after printing 5k sheets, 10k sheets and 20k sheets. In the initial state, $R_z$ is approximately $9 \mu m$, and $R_z$ somewhat decreases during continuous printing, but still is maintained at $7 - 9 \mu m$. With a conventional roller that has a powder compounding ratio of 0 (indicated by black dots), surface roughness drops to $3 - 4 \mu m$ at this time. This shows that silicon powder maintains a surface roughness at a constant level. We set the average particle diameter of silicon powder to $10 \mu m$ here. This result shows that this particle size is appropriate because surface roughness by silicon powder after continuous printing is almost the same as the initial surface roughness created by grinding.

Figure 4 shows the changes of printing density during continuous printing. With this new roller, printing density is maintained to 1.35 or more. This is because surface roughness is maintained at almost the same level.

With a conventional roller with a powder compounding ratio of 0, printing density drops to about 0.95. This is because surface roughness decreases.

3.3 Dependency of resistance on environment

Figure 5 shows the changes of resistance depending on the environment. The resistance at low temperature / low humidity is 4 times when at high temperature / high humidity. If a urethane rubber roller with ionic conduction roller is used, this is about 80 times. As this result shows, this new roller excels in environmental stability.

3.4 Chemical reaction with drum

To check the chemical reaction with the drum, the roller was contacted to the drum at a constant pressure. This status was continued for 22 hours under a 90% humidity environment, while changing environmental temperature, and the degree of reaction was evaluated by the adhesive force between the roller and drum. Figure 6 shows the result of this evaluation.
Unlike urethane roller with the ionic conduction roller, this roller has no adhesive force with the drum, indicating fine stability in terms of chemical reaction.

3.5 Physical characteristics of roller material of this development

Table 1 shows the physical characteristics of the roller material of this development. Since the roller material of this development is complex, the adhesive strength between silicon powder and base rubber tends to be the problem, but this did not become a problem because both are made from the same quality materials. As a result, the tensile strength is about 50 kg/cm², which is much greater than urethane. Rubber hardness is JIS - A37, which is relatively soft. Rebound resilience, which is correlated with deformation, is greater than urethane, indicating that this rubber is stable with little deformation.

4. Conclusion

The market is demanding high-speed and high resolution printing. The demand for developing rollers, which have a much lower rubber hardness, higher charging properties with toner, and low surface roughness and has the durability to maintain surface roughness, will increase.

5. Reference