Influence of Toner Particle Shape and Size on Electrophotographic Image Quality

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The influence of shapes and sizes of toner particles on electrophotographic image quality was studied, using a high-resolution laser beam printer. Six kinds of toners with different particle shapes and sizes were prepared in this study—two irregular, two quasispherical, and two spherical. All the toners were charged at almost the same values of q/m by mixing with ferrite carriers. An electrostatic latent image on the photoreceptor of the laser beam printer was developed by the dual-component magnetic brush development method. Images, both as developed on the photoreceptor before the transfer and fixed on the recording medium, were evaluated by optical microscopy. Effects of toner particle size and shape on as-developed images on the photoreceptor and on fixed images on the recording medium were studied. The quality of fixed images on the recording medium depended on both the shape and the size of the toner particle. Results were confirmed by the measurement of MTF of the fixed images on the recording medium. It was concluded that toner size plays an important role in as-developed images on the photoreceptor and that toner shape is further important for the final images. It is suggested that high-quality images are made by optimizing the combination of toner particle size and shape and electrophotographic process parameters.

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Introduction

High-quality printer image output is required in view of recent developments in electronic publication and desktop publishing. Laser beam printers are commonly used for that purpose. To improve the image quality of the laser beam printer, many attempts have been made to optimize the optical system, the electrophotographic process, the mechanical system, etc. For example, a decrease in the diameter of the exposure beam and high accuracy of exposure location are desired in the light-scanning system. Control of the process stability and the mechanical system is very important. In addition, electrophotographic developers play an important role in the quality of electrophotographic image outputs.[1] Utilization of smaller particle size toners was proposed to be effective in obtaining high image quality.[2] Practical use of the smaller particle size toners, however, has many problems, such as low fluidity due to cohesion, increase in q/m, and low cleaning efficiency. Further, both the crushing efficiency and classification accuracy decrease when producing such toners by the conventional pulverizing method, resulting in high cost.[1,3]

Generally speaking, toners with spherical shape can be expected to give good developing characteristics and high final image quality. For that reason, quasispherical toners have been developed by modifying the particle shape of pulverized toners with the aid of heating, and some such toners have been put to practical use. Moreover, there have been several reports recently on production of toners by the chemical polymerization method, and some of them have also been put to practical use.[4–6] The chemical polymerization methods can be divided into emulsion polymerization, suspension polymerization, and seed swelling polymerization.[1,7] The charging level of the polymerized toners can be controlled in the same way as conventional pulverized toners.[4,8,9] Spherical toner particles can be obtained by the chemical polymerization method, which bring about high fluidity and low cleaning efficiency.[10] Therefore, some polymerized toners are somewhat deformed. However, it is said that image quality depends strongly on the electrophotographic process even when using polymerized toners, which means that good images can be obtained in some cases and not in other cases.

There are basically three types of toner particles: pulverized ones with irregular shape, quasispherical ones formed from pulverized toners, and polymerized spherical ones. There are many reports on each type individually, but few reports comparing developing characteristics among the three types of toners.[5,11,12]

In this study, several toners with various particle shapes and sizes have been prepared, and influence of the shape and size on image quality has been examined. We describe experimental results on output images by the use of the various toners in a laser beam printer. First, fundamental toner characteristics prepared in this study are described, and the images on the photoreceptor before the transfer step and the fixed images on paper are presented. The image quality is evaluated by the modulation transfer function (MTF). Finally, the influence of the toner particle shapes and sizes on the final image is discussed.

Experimental

Preparation of Toners. Three types of toners with various particle shapes were prepared, using polystyrene-acrylic resin. First, two kinds of irregularly shaped toners differing in mean particle size were prepared by a conventional pulverizing method. The as-pulverized toner was classified into two groups, one having mean particle size 10 μm and the other 7 μm. The two are referred to as IR-U and IR-F, respectively. Here, IR means irregular and -U and -F mean usual particle size and fine particle size, respectively. Similar notation is also applied to two

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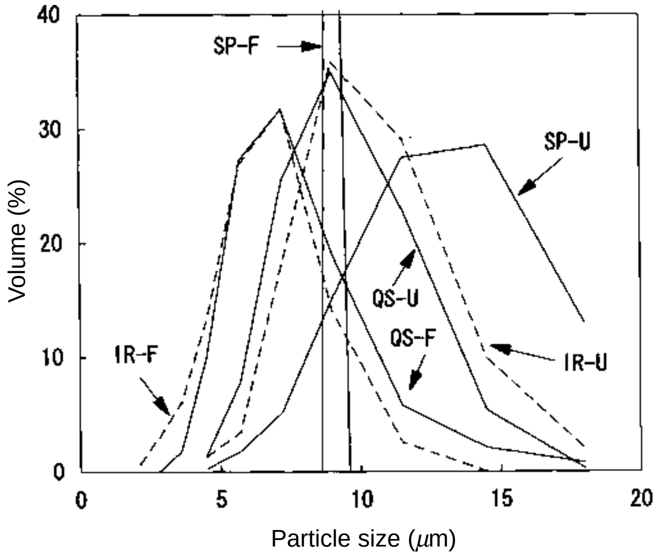

Figure 1. Particle size distribution of prepared sample toners.

additional groups of toners. Second, quasispherical toners were prepared by modifying the pulverized toners with the aid of heat. Two kinds of quasispherical toners, referred to as QS-U and QS-F, were formed from IR-U and IR-F, respectively. Here QS means quasispherical. The mean particle sizes of the quasispherical toners were the same as those of the original pulverized toners. Third, spherical toners were prepared by the suspension polymerization method and seed swelling polymerization method. The former gave a spherical toner with mean particle size of 14 μm (SP-U), and the latter gave a toner of 9.1 μm (SP-F). Here SP means spherical. In all, six kinds of toners were prepared for this study. The particle size distributions of the toners are shown in Fig. 1. The particle size distribution of the toner SP-F is very sharp, 9.1 ± 0.5 μm, whereas the particle size distribution of the toner SP-U is relatively wide. The difference is due to the polymerization methods. Figure 2, which shows SEM micrographs of all the toners, indicates the shape difference among them. The fundamental characteristics of the six toners used in this study are tabulated in Table I. All the toners are of negatively charging type.

Experimental Condition. To study the influence of toner shape and size on image quality, electrophotographic output images were obtained, using the sample toners. For that purpose, a conventional laser beam printer with recording density of 600 × 600 dpi (dots per inch) was used in this study. This printer employed an α–Se photoreceptor drum, dual-component magnetic brush development process, electrostatic corona transfer process, and heat roll fusing process. The photoreceptor drum was rotated at the peripheral velocity of 100 mm/s, and the developing magnetic roller with a sleeve was located at a gap of 2 mm from the photoreceptor and was rotated at the peripheral velocity of 290 mm/s in the opposite direction.

Each toner was mixed with a polymer-coated ferrite carrier of mean particle size 70μm to form an electrophotographic developer. Toner concentration of the developer was 7 to 8 wt%. The developer was agitated to tribocharge the toner to q/m of – 25 to – 30 μ C/g. All experiments were made at room temperature.

Results and Discussion

Images on Photoreceptor. To clarify the influence of toner characteristics on the image quality in the electrophotographic process, toner images on the photoreceptor before transfer to plain paper were subjectively evaluated first. The image resolution, line width fluctuation, and blur were analyzed by optical microscope

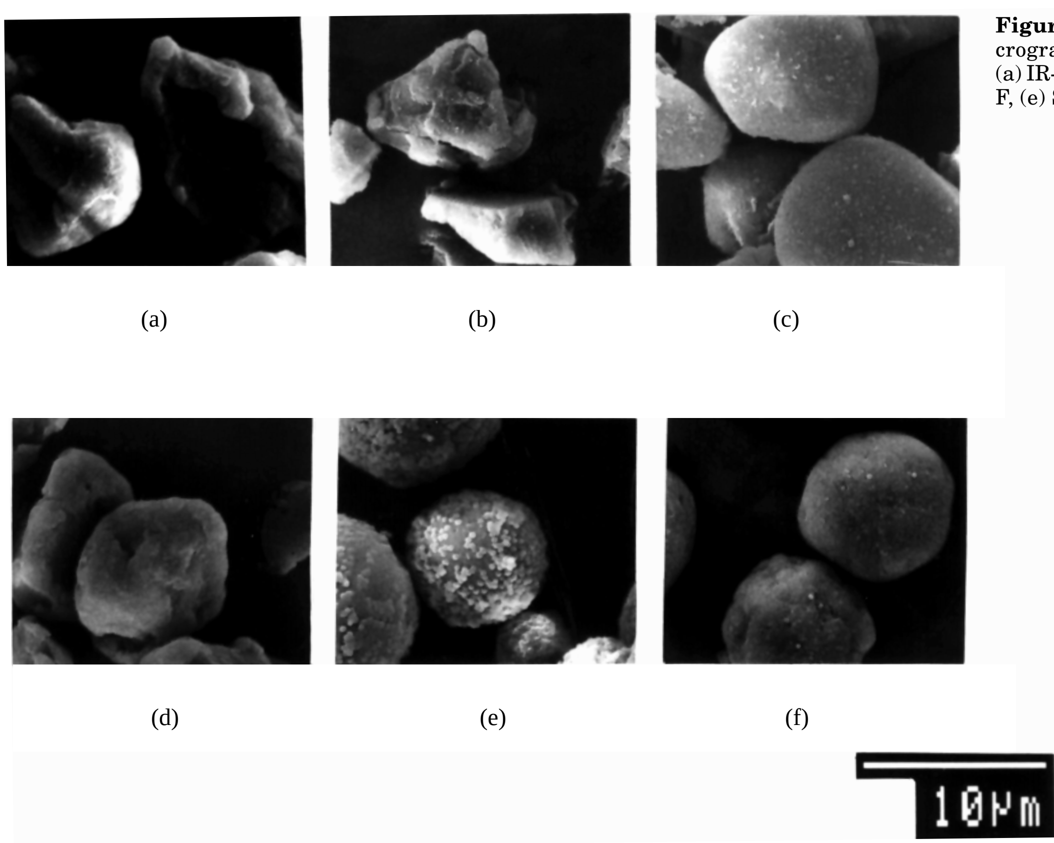

Figure 2. Scanning electron micrographs of the sample toners. (a) IR-U, (b) IR-F, (c) QS-U, (d) QS-F, (e) SP-U, and (f) SP-F.

TABLE I. Fundamental Characteristics of Sample Toners, and Quality and MTF of Images

Notation	IR-U	IR-F	QS-U	QS-F	SP-U	SP-F
Shape	Irregular		Quasi spherical		Spherical	
Preparation method	Conventional pulverizing		Modifying the pulverized toners with the aid of heat		Suspension polymerization	Seed swelling polymerization
Mean particle size (μm)	10	7	10	7	14	9.1
Image quality on photoreceptor	Better	Best	Better	Best	Better	Poor
Image quality on paper	Better	Second Best	Second best	Best	Poor	Poor
MTF	Better	Second Best	Best	Best	Poor	—

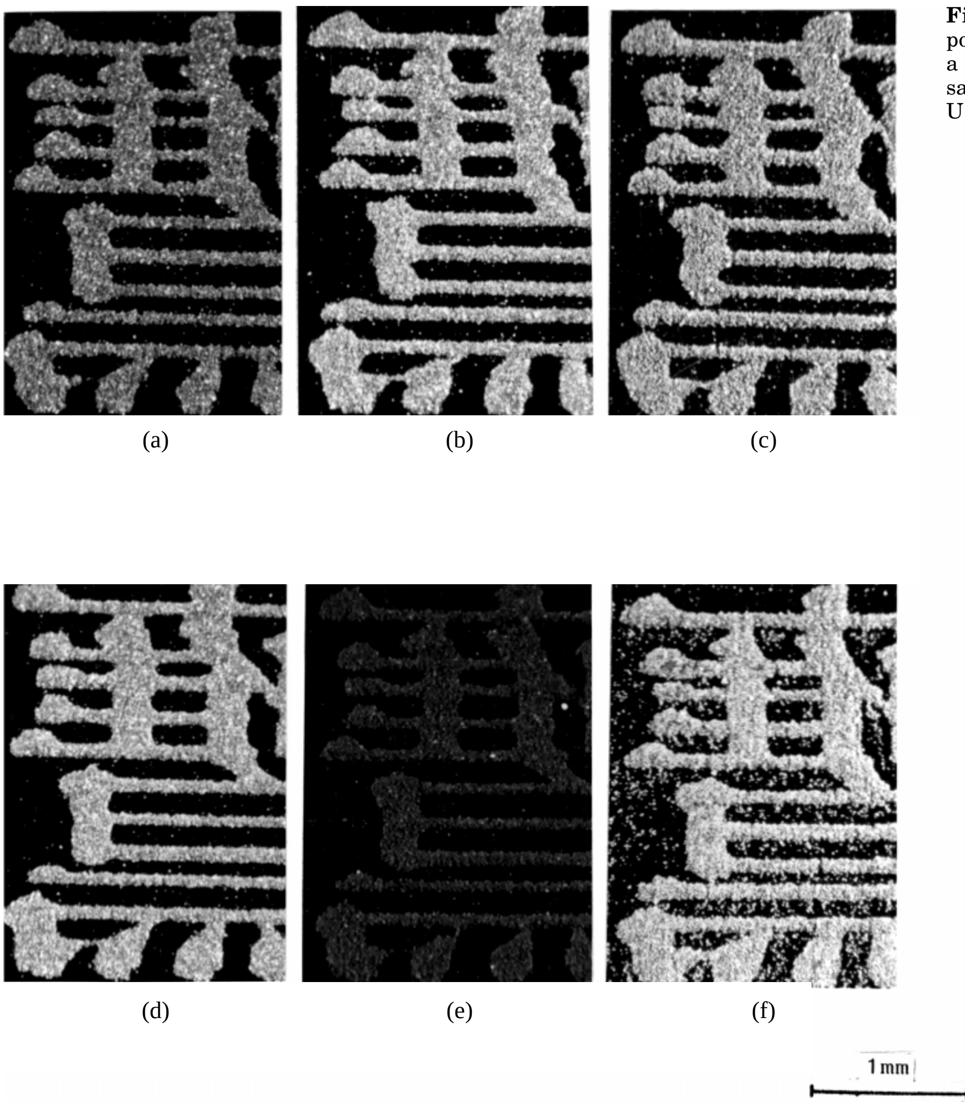

Figure 3. Photomicrographs of an 8-point-size Japanese kanji character on a photoreceptor developed by the sample toners. (a) IR-U, (b) IR-F, (c) QS-U, (d) QS-F, (e) SP-U, and (f) SP-F.

observation. Photomicrographs of an 8-point-size Japanese kanji character developed by the toners are shown in Fig. 3.

The image quality obtained with toners IR-F and QS-F was better than that with other toners. Toners IR-U and QS-U had almost the same developing characteristics and gave the second best image quality. As to the irregular and quasispherical toners, the fine particle size toners (IR-F, QS-F) gave better image quality than did the usual size toners (IR-U, QS-U). This result indicates that toner size is more effective than toner shape in determining image quality on the photoreceptor. In addition, the spherical toner SP-U gave image quality close to that with IR-U and QS-U, in spite of the large mean particle size and broader particle size distribution. This may be attributable to the toner particle shape. The adhesion force of a spherical toner particle onto a carrier surface is weaker than that of irregular or quasispherical toners, if they have the same value of q/m.[13] As a result, the spherical toner transfers more faithfully from the carrier surface to the electrostatic latent image on the photoreceptor.

On the other hand, the spherical toner SP-F prepared by the seed swelling polymerization gave the poorest image quality among the six sample toners, as can be seen

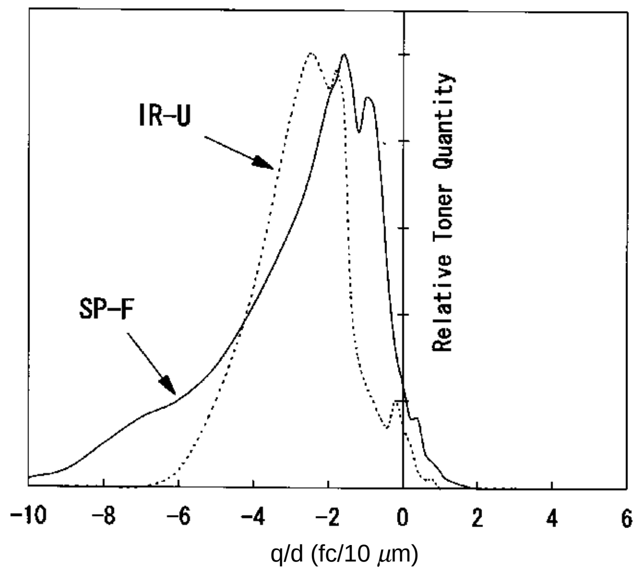

Figure 4. Toner charge distribution of IR-U and SP-F.

in Fig. 3. The image density obtained with the toner SP-F was not uniform, and there was a considerable amount of fog in the nonimage area. To investigate this result, the toner charge distribution was measured. The result is given in Fig. 4. Toner SP-F showed a wide *q*/*d* distribution and contained a considerable number of wrong-sign particles compared with the toner IR-U, which gave better image quality. The poor image quality with the toner SP-F can be attributable to the wide *q*/*d* distribution and wrong-sign particles. The reason that the spherical toner with the sharp particle size distribution (SP-F) has a wide *q*/*d* distribution and many wrong-sign particles is not certain at this moment. The carrier used in this study may not be suitable for Toner SP-F. It can be seen that the developing behavior of the spherical toners is different from that of the irregular and quasispherical toners.

Final Images on Paper. Next, the influence of the transfer and fusing processes on the image quality was examined from the standpoint of toner shape and toner size. Transferred and fixed images on plain paper were subjectively evaluated in the same way as the evaluation of image quality on the photoreceptor. The photomicrographs of the final images obtained by transferring and fixing the images on the photoreceptor (Fig. 3) are shown in Fig. 5.

The fine quasispherical toner QS-F gave the best final image among the six kinds of toners used in this study. The image obtained by this toner is very clear and free of line-width fluctuation and blur. Note that this toner also gave the best image on the photoreceptor. Toners IR-F and QS-U gave the second best images on the plain paper, with some line-width fluctuation and blur. Note that Toner IR-F had given one of the best images on the photoreceptor, as had Toner QS-F. Toners QS-F and IR-F gave images of almost the same quality on the photoreceptor. However, the image quality with Toner QS-F could be kept through the transfer and fusing processes, whereas the image quality with Toner IR-F deteriorated. Toner IR-U gave an image on the plain paper in which the line width increased or decreased, depending on the position of the Japanese kanji character. These results indicate that the toner shape influenced the image quality during the transfer and fusing processes. This was considered to be because those irregular toner particles may not be transferred evenly during the transfer process because of their wide adhesion force distribution.[13]

The images obtained by the spherical toners SP-U and SP-F deteriorated remarkably during the transfer and fusing processes. This was considered to be because the spherical toner particles may be scattered during the transfer process on account of their weak adhesion forces. To describe more fully, the corona transfer process with a small gap between the photoreceptor surface and the paper was employed in this study. Toner particles adhered to the photoreceptor surface weakly may be transferred even at places other than normal image area, resulting in a wide spread of toner particles on the plain paper. This result suggests that a roller transfer method may be preferable to the corona transfer method for the polymerized spherical toners. The quality of images on the photoreceptor and the paper obtained by the sample toners is summarized in Table I.

MTF. Subjective evaluation of the image quality was described above. The resolution of fixed images on the plain paper was evaluated quantitatively by the MTF. For that purpose, several images ranging from solid pattern to line pairs of 5.9 lp/mm were printed by the laser beam printer, and optical density distribution of those images was measured in a microdensitometer. The slit size was set as 200 × 50μm for the measurements.

The optical density contrast is given by the following equation:

$$C(n) = \frac{I_M(n) - I_m(n)}{I_M(n) + I_m(n)}, \tag{1}$$

where n is the spatial frequency (line pairs/mm), $I_M(n)$ is the maximum image density, and $I_m(n)$ is the minimum image density.[14] Then MTF is given by the following equation:

$$MTF(n) = \frac{C(n)}{C(0)}, \tag{2}$$

where $C(0)$ is the contrast for 0 lp/mm.

Experimental results of the MTF measurements on the images printed with the sample toners are given in Fig. 6. The fine quasispherical toner, QS-F, gave an excellent result, which agreed with the result of the subjective evaluation. The quasispherical toner with usual particle size, QS-U, gave almost the same image quality of Toner QS-F in terms of MTF. This result was a little bit different from that of the subjective evaluation. The reason may be that the image quality evaluation by MTF is based on the evaluation of relative image density, as can be seen in Eq. 1. Toner IR-F gave the next image quality in terms of MTF, and Toner IR-U did not give as good a result. Toner SP-U gave the poorest MTF result. The MTF of the image by Toner SP-F could not be measured, because the image was so poor. As a whole, these results agreed with those of the subjective evaluation. The results of image quality evaluation by means of MTF are also given in Table I.

In summary, the fine quasispherical toner QS-F gave the best image among the sample toners from the standpoints of both the subjective evaluations and MTF. This result may be attributable to the best matching of the toner, the carrier and the electrophotographic process.

Conclusions

Several toners with various toner shapes and toner sizes were prepared, and the influence of the shape and size of the toner particles on image quality was examined by subjective evaluation and by MTF measurements. The following results were obtained:

1. The fine quasispherical toner gave the best final image.

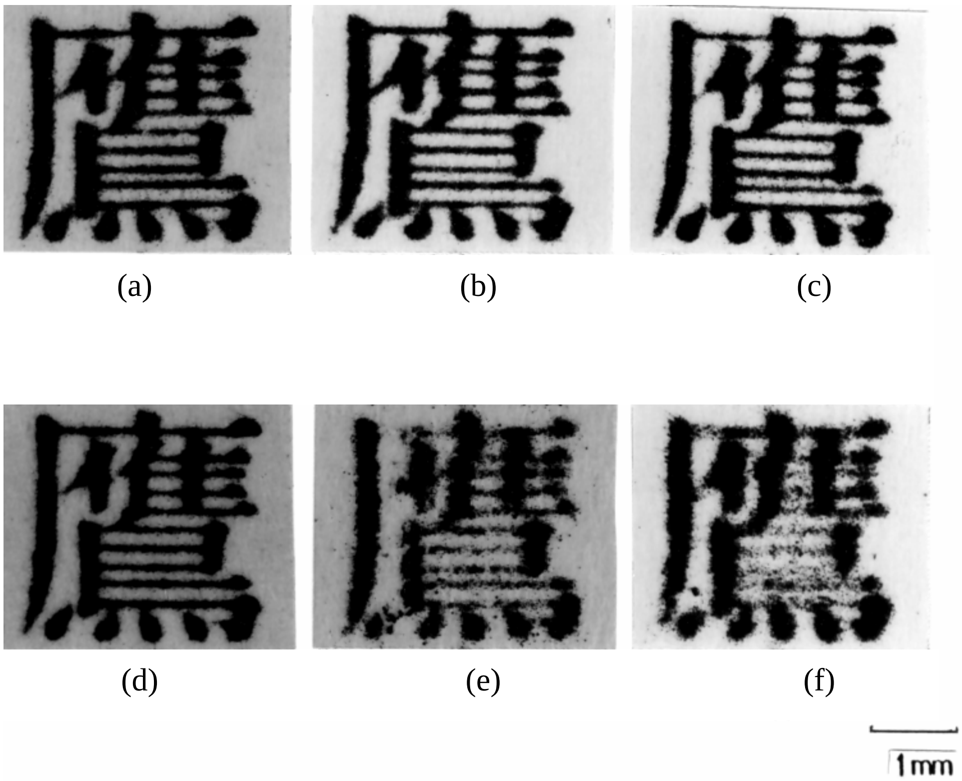

Figure 5. Photomicrographs of fixed output images on a plain paper obtained by the sample toners. (a) IR-U, (b) IR-F, (c) QS-U, (d) QS-F, (e) SP-U, and (f) SP-F.

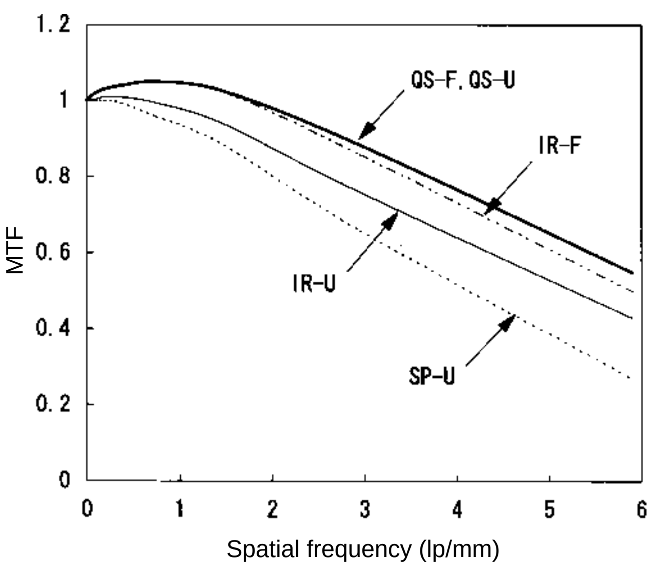

Figure 6. Modulation transfer function of fixed output image on the paper obtained by using the sample toners. (a) IR-U, (b) IR-F, (c) QS-U, (d) QS-F, and (e) SP-U.

2. Toner particle size played an important role in the developing process.
3. Toner particle shapes influenced image deterioration during the transfer and fusing processes.
4. Unfortunately, the polymerized spherical toners did not give good results in this study.
5. Optimizing the combination of toner, carrier and the electrophotographic process is important for getting excellent images.

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