New Digital Pad Printing Technology Using Inkjet Printers

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Abstract

When printing with conventional UV-curable inkjet printers, it is almost impossible to obtain high-resolution images on the uneven printing media such as molded plastic products with undulations of more 3mm. This study is related to the new digital pad printing technology, which produces high-quality images on such uneven surfaces. The process to produce images is as follows: (1) Inkjet printing is carried out on a heated silicon rubber film with UV curable ink diluted with an organic solvent. This solvent evaporates immediately after the ink droplet reaches the film surface, making the ink viscosity higher. Thus the spread of the printed ink dot stops. This results in sharp printed images. (2) A soft pad is applied to the backside of a silicon rubber film, which can be pressed against an object, thereby transferring the ink image onto the object's surface. (3) Finally the UV irradiation makes the ink hard. Through this process, we can decorate various objects with high-quality images.

Introduction

Conventionally, various methods are provided to print images on the curved surfaces. They include the In-mold Decoration(IMD) method, pad printing, water transfer printing, and TOM [1] three-dimensional overlay method manufactured by FUSE KOGYO Co. Ltd. These conventional methods require creating the press plate for printing and have a disadvantage of high cost when carrying out small amounts of printing.

As a system to print images on the molded three-dimensional product, the 3D sublimation dye transfer system is provided by IDT Corp [2]. This system does not require the press plate; however, it has a disadvantage that printing is limited to the polyester series where decorative materials can be colored with a sublimation dye.

Since the inkjet printing system can print images without contact, it can print them onto some extent uneven surfaces. However, when a gap is large for printing, the ink droplet speed is rapidly slow down due to air resistance, which results in instable printing. The gap that can directly print high-definition images on a three dimensional product such as a molded product is limited to few millimeters by the inkjet printer. Therefore, images cannot be directly printed on the rough uneven surfaces and not decorated.

We have tried to develop the digital pad printing system which makes use of the pad printing advantage of decoration on the rough uneven three-dimensional product and can also decorate images on-demand using the inkjet technology without creating the press plate. We have an idea of using two kinds of inks such as the UV ink diluted with organic solvent and the normal UV ink. This paper shows the experimental results when using the UV ink diluted with organic solvent.

Experimental

Digital pad printing processes

Two kinds of processes of the proposed digital pad printing technology are described below.

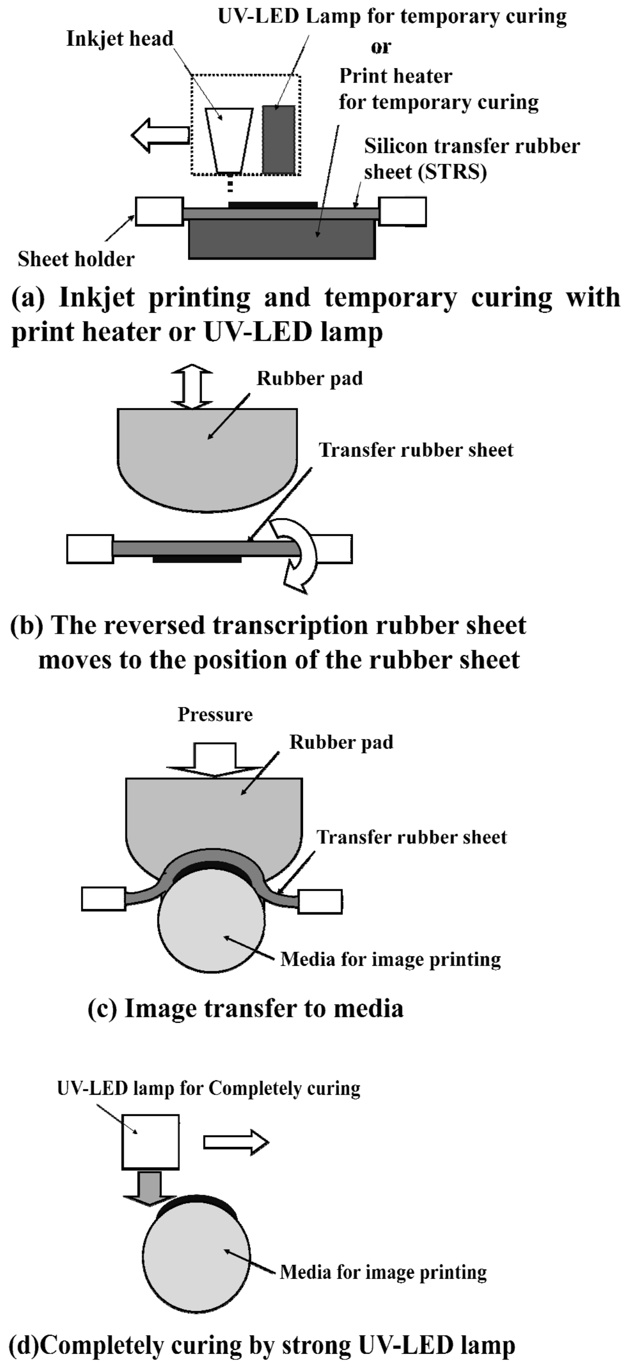

Figure 1. *Process of the digital pad printing proposed in this study. We can use the following two kinds of methods to harden ink temporarily: (1) Curing ink with UV light irradiation and (2) evaporating solvent from ink.*

(1) Digital printing and reduced decrease in ink dot spread

Figure 1 shows the process to fix final images onto the media or products to be decorated with inkjet-printed images. The silicon transfer rubber sheet abbreviated as STRS is an intermediate image-capturing material which transfers inkjet images to the surface of printing media. One of two kinds of methods in this study is to use SUV ink [3] for printing. The SUV ink is prepared by diluting ordinary UV-curable ink with organic solvents. Since the STRS is heated from the underside, the organic solvent in the SUV ink can easily evaporate to make the ink viscous. Consequently the spread of ink dots is decreased and finally sharp images are obtained.

Another method in this study is to use ordinary UV-curable ink which is easily made viscous only with irradiating UV light.

(2) Transfer of printed images to the media

As seen in Figure 1 (c), a soft rubber pad presses the STRS from its backside to transfer the viscous ink onto the media for image printing.

(3) Image fixing with UV-LED light irradiation

As seen in Figure 1 (d), UV-LED light causes the hardness of the ink on the surface of the media. Finally inkjet images are fixed there.

Silicon transfer rubber sheet (STRS)

As described above, we have used silicon rubber sheet, which is called STRS in this study, for an intermediate image-capturing material. Silicon rubber sheets, commercial products manufactured and sold by TORAY Co. are used in this study.

Pressure has been applied manually from the backside of the STRS with using a plastic round bar.

Control of ink viscosity by adding organic solvent

Effect of organic solvent on ink viscosity

Figure 2 shows that the viscosity of UV-curable inks can be decreased by adding organic solvent. Even if UV-curable inks containing no organic solvent show different viscosity from each other, similar viscosity can be brought finally by the addition of organic solvent. This fact is shown in Figure 2 (a). Figure 2 (b) is the part of Figure 2 (a) in the range of solvent content from 40 to 100 wt%., where the vertical axis is enlarged. Although inks A, B, and C have initial viscosity of 50, 100, 200 mPa·s, respectively, their viscosity has come to the same value, 1 mPa·s after sufficient dilution with organic solvent. Thus we can adjust the viscosity of ink to the aimed value (about 3-12 mPa·s) by adding organic solvent and lead smooth ink ejection from an inkjet print head.

The ink with higher intrinsic viscosity is favorable to obtain better image quality with high resolution because the fluidity of ink is decreased with increasing the viscosity.

Control of drying speed for dilution solvent

Since the STRS is heated from the backside, solvent added in the UV-curable ink can evaporate in a short period of time and the viscosity becomes higher (Figure 1 (a)). This process reduces the spread of ink on STRS surface and consequently sharp images are expected to be brought.

We have examined the speed of evaporation of three kinds of organic solvents whose boiling temperatures are 120, 146, and 175 ℃.

Each solvent of 10 ml in Petri dish with an internal diameter of 58.4mm has been kept in an oven at 50, 70, or 90 ℃. The results are shown in Figure 3 (a), (b), and (c), where each vertical axis shows the percentage of the remaining solvent after being kept for a certain time in the oven. The horizontal axis shows the time (min) that

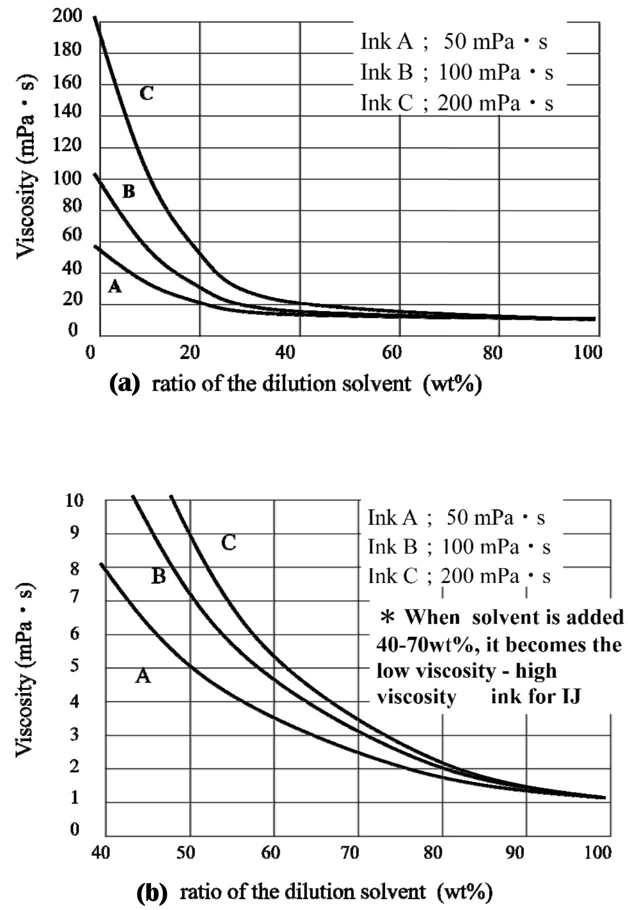

Figure 2. *Viscosity of ink with adding organic solvent.*
Intrinsic viscosity: 200mPa·s for ink A, 100mPa·s for ink B, and 200mPa·s for ink C. Figure 2 (b) *is the part of Figure 2* (a) *in the range of solvent content from 40 to 100 wt%., where the vertical axis is enlarged.*

Petri dish has been kept in the oven.

We have put the following assumptions based on our experiments carried out prior to this study.

(1) The complete drying time in the Petri dish, which is written Ts below, is three times as much as the time when 50% of the solvent evaporates.

(2) The drying time is proportional to the initial thickness of ink or the ink thickness at drying time of zero.

From the results of Figure 3, we can calculate the time when organic solvent evaporates completely, resulting in the temporary hardening of ink at the stage of Figure 1 (a). The time in this case is written Td below. To estimate the value of Td, we have calculated the dryness coefficient (K) firstly. In our experiment with 10 ml ink in Petri dish, the height of ink (D) is 3.7 mm. On the other hand, when inkjet printing is carried out with 24 pico-liter ink droplet and 600 dpi, we can calculate that the ink thickness (L) is 13.9 μm. Thus $K = L/D = 13.9x10^{-3}/3.7 = 3.76x10^{-3}$. Using the values of K and Ts which can be read from Figure 3 (a), (b), and (c), we can calculate Td based on the following equation: Td = K x Ts. The values of Td are listed in Table 1.

Table 1 Relation between solvent boiling temperature and estimated drying time at the stage of Figure 1(a).

Boiling Temp. / Drying temp.	120℃	146℃	175℃
50℃	6.1 sec	13.5 sec	60 sec
70℃	3.6 sec	8.6 sec	21 sec
90℃	2.7 sec	4.9 sec	9.9 sec

The solvent easily evaporates when the boiling temperature is low; therefore the drying speed becomes faster. To prevent the spread of ink, the solvent with the lower boiling temperature and the faster evaporation speed is desirable. However, when the solvent with the boiling temperature 120 ℃ is used, a problem of ink ejection frequently has occurred. This phenomenon is based on the fact that the ink with too high viscosity cannot be ejected easily from print head nozzles.

It is taken for granted that higher drying temperature results in shorter drying time. From the viewpoints of safety and stable ink-ejection, however, we have decided the drying temperature of 90 degrees or less in our study hereafter.

Results and Discussion

Quality of printed images

Figure 4 shows the test image (girl) at the stage of Figure 1 (a) . Figure 4 (a) shows the printed image with the UV ink with the intrinsic viscosity 200mPa･s, and Figure 4 (b) shows the printed image with the SUV ink that is produced by adding organic solvent to 10000 mPa･s UV ink. Here, organic solvent of boiling point 175 ℃ has been added.

Images printed on the silicon film with the SUV ink are hardened by irradiating UV light, but they cannot be fixed because they do not adhere to the film. In this study, the image before transfer was directly printed on a white PET film, temporarily hardened, and then hardened by UV irradiation.

Figure 5 shows the image that was printed to the transfer rubber sheet using the SUV ink of the Figure 4 and then transferred to PET. The SUV ink image temporarily hardened on the STRS can be transferred to PET by only pressing it from the backside. Similarly, it can be also transferred to the paper.

Figure 6 shows the print image when changing the boiling temperature of dilution solvent. The ink with the solvent boiling temperature 120℃ cannot be printed due to a problem of ink ejection. Large difference has not been found between the results with the solvents of boiling temperatures 146 and 175 ℃.

Making the initial viscosity higher instead of the solvent boiling temperature has remarkable effect on prevention of the ink blot.

Figure 7 shows the results of printing characters on the white PET film. This indicates that characters can be printed without the expansion of the ink.

Advantages of SUV ink

Since ordinary UV-curable Ink has no volatile solvent, there is no conflict with VOC regulations. The biggest problem in SUV ink is losing the most important feature of UV-curable Ink that it does not contain any VOC. However, the SUV ink has enough advantages to make up for the problem as follows.

Firstly, although extremely viscous monomer and oligomer cannot be used in the ordinary UV-curable inks, these compounds can be used in the SUV. This fact will expand the range of choice of useful compounds and finally give the solutions to the various issues such as adhesiveness, flexibility, elasticity, and safety to human body.

Secondly, similarly to the printing with conventional solvent ink, high-gross printed images can be obtained.

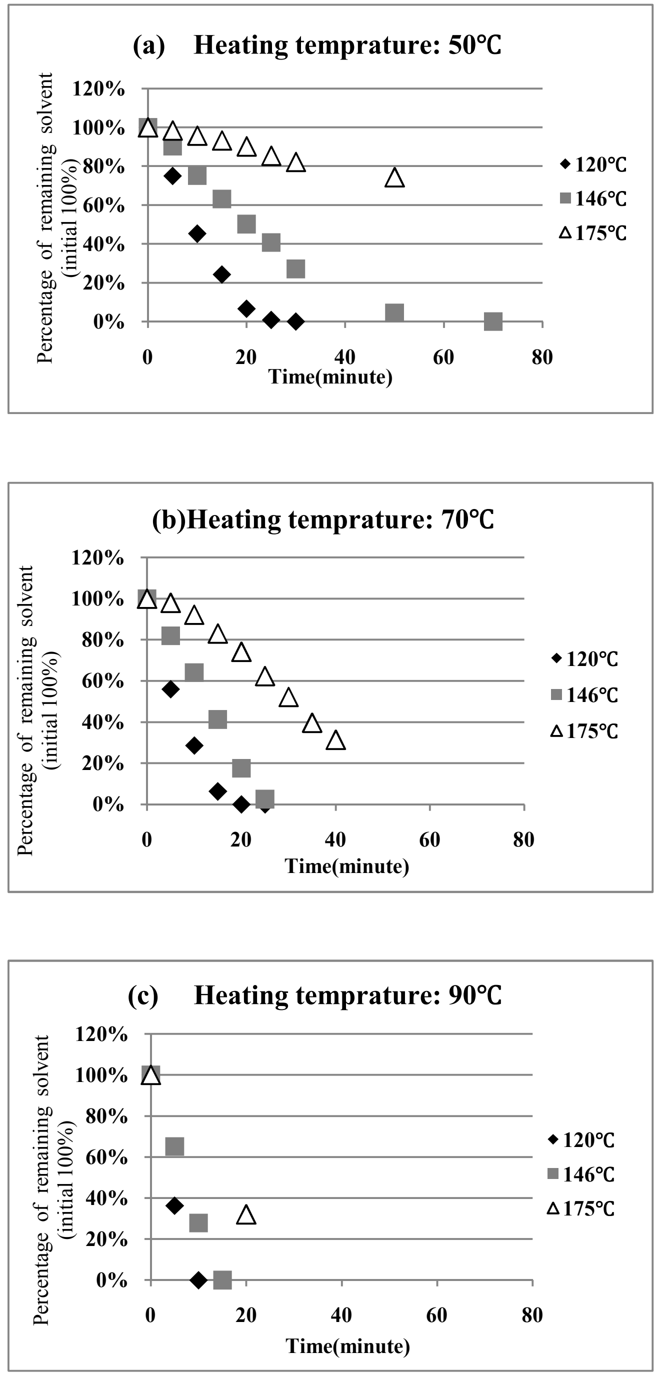

Figure 3. Percentage of remaining solvent in SUV ink.
Boiling temperature of solvent: ◆ 120℃, ■146℃, △175℃.
Heating temperature of oven: (a) 50℃ , (b) 70℃, and (c) 90℃.

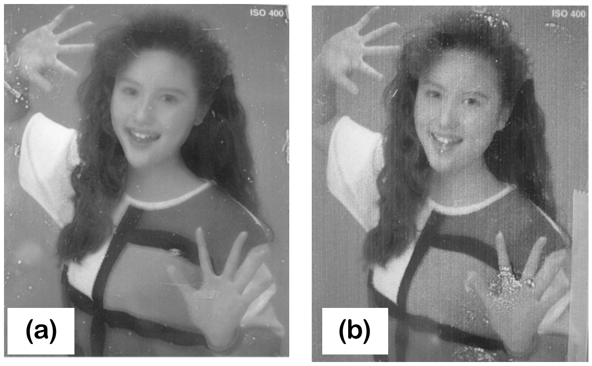

Figure 4. *Direct print examples by SUV ink.*
Initial viscosity: (a) *200 and* (b)*10000 mPa·s.*

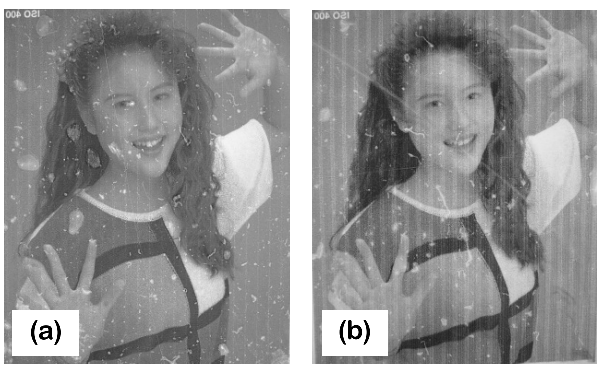

Figure 5. *Transferred print examples by SUV ink.*
Initial viscosity: (a)*200 and* (b)*10000 mPa·s.*

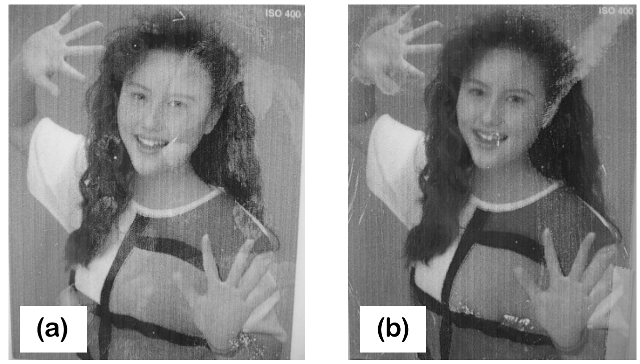

Figure 6. *Direct print examples by SUV ink.*
Boiling point of solvent: (a)*170℃ and* (b)*146℃.*

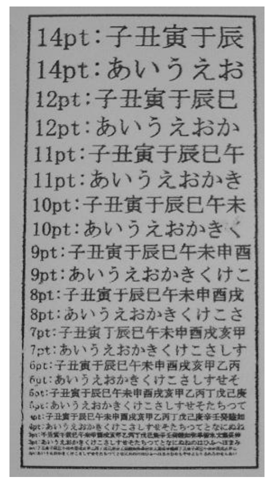

Figure 7. *Direct print sample by SUV ink on PET film.*

Summary

We have proposed the basic process of the digital pad printing technology using inkjet printers.

1. The process to produce images is as follows:
   (1) Inkjet printing is carried out on a heated silicon rubber film (STRS) with UV curable ink diluted with an organic solvent.
   (2) A soft pad is applied to the backside of a silicon rubber film, which can be pressed against an object, thereby transferring the ink image onto the object's surface.
   (3) Finally the UV irradiation makes the ink hard.
2. Printing quality is affected by the fluidity of ink on the STRS. When the ink is temporarily hardened, the ink does not spread and sharp images can be obtained.
3. The following two kinds of inks have been tested: UV ink diluted with organic solvent (SUV ink) and normal UV ink. We have found that the SUV ink brings good results in our Digital Pad printing system.
4. Higher initial viscosity of the SUV ink, that is the viscosity of intrinsic UV-curable ink containing no organic solvent, is better to obtain good print quality.

We plan to solve several issues for practical use in our next stage. For example,

(1) To print images using YMCK 4 colors
(2) To develop new material for STRS and establish the best transfer conditions
(3) To apply to curved surface printing

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Author Biography

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