Visualization of contact patterns of thermal printhead for indirect thermal transfer printing

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Abstract
Printers often face problems with large power consumption, resulting in the development of various power saving techniques. Such techniques for indirect thermal transfer printers covered in this study are also progressing. For this type of printer, most of the required electric power is consumed during the ink transfer process, in which ink on a transfer belt is heated using a heating roller with large heat capacity. To reduce the heat capacity of the heating system, the use of a thermal printhead with a low thermal capacity has been proposed. Even at low power, such a thermal printhead will immediately reach high temperatures within a specified area, shortening the warm-up time and leading to lower printer power consumption. However, thermal prinheads have two problems with contact heat transfer. The first is that the thermal printhead is less likely to deform than the soft heating roller. Secondly, since the wiring for power supply is complicated, irregularities of several μm are formed on the surface of the printhead, resulting in the limited heat transfer. To evaluate these effects, distribution of contact pressure with respect to surface waviness was analyzed using the finite element method. In this study, we observed the real contact area using a wide-field laser microscope and evaluated the validity of the FEM analysis. We succeeded in visualizing the contact pattern by pressing the ultra-high transparent silicone rubber and the transparent plastic film against the thermal printhead. As a result, it was confirmed that the FEM simulation results agree with the experimental ones.

Keywords: Thermal printhead, Laser microscope, Real contact area, Waviness, Visualization

1. Introduction

In laser printers, a fixing heater is used to fuse the pigment in place on the printing paper. After receiving print data, it takes several tens of seconds for the fixing heater to reach a predetermined temperature, after which printing commences. Since the heat capacity of the fixing heater is generally large, most of the electric power required for the laser printer is consumed by the fixing heater in the fuser unit. To solve these problems, various power saving techniques for heaters have been developed (Onodera et al., 2016, Maeda et al., 2014).

Power saving techniques have also progressed in indirect thermal transfer printers covered in this study. The principles of the indirect thermal transfer printer are shown in Fig. 1 (Ukai et al., 2008), characterized by use of an indirect transfer belt. An image for printing will be first constructed on the transfer belt with an ink ribbon and the thermal printhead. Then, the image on the transfer belt is moved to another place for the fixing and transferred to the printing material by heating and pressing. In this printing method, it is even possible to perfectly print an image on uneven surfaces which are difficult to directly print on by ordinary printers. This is due to the transfer belt deforming flexibly and following the uneven surface. The power consumption of this printing system is concentrated in the
transferring and fixing processes as a conventional heating roller with large heat capacity is used as the heater in the transfer process, as shown in Fig. 2 (a). To reduce the power consumption, a thermal printhead has been proposed as shown in Fig. 2 (b). Because the thermal printhead has a smaller volume than the heating roller, it has a lower heat capacity (Puterbaugh et.al, 1967, Joyce et. al., 1967) and can immediately reach high temperatures necessary for fixing. Fine power control of the thermal printhead is also possible. This means that the surface temperature of the thermal printhead can be accurately controlled under low power consumption. Hence, it is expected that the warm-up time of the printer can be shortened, resulting in power savings.

There are, however, two problems with the contact situation between the thermal printhead and the transfer belt. The first is that the thermal printhead is less likely to deform than the soft heating roller because the substrate of the thermal printhead is a hard glass plate. The second is that the complex wiring to supply the power causes the irregularities of several µm on the surface of the thermal printhead, preventing intimate contact. For this reason, it is important to observe the contact condition of the surface, i.e. the distribution of real contact area.

Real contact area has played an important role in the field of tribology since it was observed experimentally (R. Holm, 1967). The formulation of real contact area has become the fundamental factor in analyzing tribological problems concerning friction, wear and lubrication. Archard used the real contact area to construct his elementary theory of adhesive wear (I.G. Goryacheva, 1967). A number of theories, taking the distribution of real contact area into consideration, emerged predicting the wear amount after Archard. Thermal contact resistance can also be considerably affected by the distribution of real contact area because heat is transmitted to the opposing surface through real contact points. Distributions of contact pressure and real contact area between two rough surfaces have been obtained by computer simulation on the basis of measured surface profiles (for example, N.K. Myshkin et. al., 1997, Kogut, L. et. al., 2003). In contrast, they have rarely been obtained by experiment.

There are several methods of measuring the real contact area, such as measurement of electrical and thermal contact resistance, ultrasonic flaw detection (A. Takeuchi et. al., 1997), methods using colorant (T. Hisakado, 1969) and soot (K. Yamada, 1980), and contact microscope (I.V. Kragelskii, 1965, V. A. Bely et. al., 1982, N. Soda et. al., 1977, Y. Sakurai, 1952, C. Otani, et. al., 1992). Among these methods, contact microscope is the relatively simpler method, because it requires no special preparation and only one side of the contacting surfaces needs to be a transparent material.

When nominally flat solid surfaces are brought into contact, there is no guarantee that intimate contact is achieved over the whole apparent contact area, and air gaps arise in places. Due to the low thermal conductivity of air, the flow of heat between sections not in intimate contact is inhibited. Since gaps are less likely to transfer heat than the real contact area (Shimizu et al., 2005), the effect of the contact situation between the thermal printhead and the transfer belt will be large. There are two points of view, microscopic and macroscopic, when considering the phenomenon of contact heat transfer. From the microscopic viewpoint, the surface roughness of the thermal printhead (about Ra 0.2
µm) affects the amount of heat transfer as mentioned above, and is called contact thermal resistance (M.G. Cooper et. al., 1969, M.M. Yovanovich, 2005). From the macroscopic viewpoint, we must consider the effect of waviness on the surface of the thermal printhead, likely to be larger than that of the surface roughness. We believe that a numerical simulation incorporating both viewpoints will lead to optimization of the thermal printhead design.

So far, we have measured the coefficient of contact heat transfer experimentally, which is difficult to analyze using numerical simulation (Fukuoka et al., 2010), in order to incorporate the effect of surface roughness into calculations. Disregarding microscopic effects, in order to investigate the macroscopic ones we have analyzed the effects of surface waviness on the real contact situation by finite element method (FEM), which was also used to calculate the temperature distributions around the nip portions (Shih et al., 2006, Shih et al., 2008). The validity of FEM analysis must be verified experimentally. However, since there is no method for observing the wide contact area handled by the FEM analysis, verification of the FEM analysis has not yet been conducted.

The real contact area is often observed under an optical microscope (Soda and Kohno, 1977, Kawaguchi et al., 2005, Eguchi and Yamamoto, 2009, Nitta, 2007), in which case, observation with a 10× objective lens allows observation of at most a 0.5 mm square region. For this reason, observation of the engineering surface over a fairly wide region, for example 10 mm width, has rarely been conducted. In a previous study, a wide-field laser microscope was developed (Nitta et al., 2010), and a relatively wide region of contact surface able to be observed in a short time (Nitta et al., 2011).

In this study, we proposed an observation method for the real contact surface of the thermal printhead with the aid of ultra-high transparent rubber using a wide-field laser microscope. This method is expected to be suitable to evaluate the validity of the FEM contact analysis which has been performed so far. To observe the contact surface one of the mating specimens must be transparent, but the thermal printhead itself is opaque. While a glass plate is usually used as a mating material, we used transparent plastic film and transparent rubber. The distributions of the intimate contact area were clearly observed over the whole apparent contact area. Furthermore, distributions of intimate contact were similar to ones analyzed by FEM, leading to validity of the FEM analysis.

2. Experimental

2.1 Experimental equipment (wide-field laser microscope and load device)

We used a confocal wide-field laser microscope, using which a relatively large area can be observed in a short time. The major specifications of the microscope are shown in Table 1. Figure 3 (a) shows the outline of the optical path diagram of the laser microscope surrounded by the dashed lines, and the loading system for the specimens. This laser microscope uses the shrink fitter technique (Nitta et al., 2003) to fabricate the laser scanning fθ lens unit, which realizes both the characteristics of wide field and high resolution, regardless of ambient temperature change. By rotating the scanning mirror, the laser beam scanned the contact surface for inspection in the x-direction. On the other hand, by using the motor-driven linear stage the contact surface was moved up to 8 mm in the y-direction, thereby allowing the contact surface to be observed over a wide range of 10 mm × 8 mm.

The specimen was brought into contact with the glass plate by turning the feed screw, and the normal load applied to the specimen was measured with a load cell.

In a previous study, the rubber roller was pressed against the glass plate as shown in Fig. 3 (b) and the image of the contact surface was acquired over the range of 10 mm × 4 mm. At the real contact portions, the lights reflected from the surfaces of both the rubber roller and the glass plate interfered and caused zeroth order interference, e.g. destructive interference, thereby causing pixels of the real contact portions to darken as shown in Fig.3 (c). The surface of the rubber roller was finished by grinding, and the ridges on the surface made strong contact with the glass plate, leading to the contact pattern in Fig. 3 (c). As can be seen from this example, the transparent specimen should be placed on the incident side of laser light to observe the contact surface. In the preliminary experiment, we specially prepared a translucent thermal printhead instead of a glass plate because the indirect transfer belt was opaque. However, since the transparency of the thermal printhead was not sufficient for the laser light to reach the contact surface, it was impossible to observe the contact surface with this configuration. Therefore, by using transparent rubber instead of the transfer belt, we were able to observe the contact surface of the thermal printhead.
2.2 Thermal printhead for fixing unit

The cross sectional profile of the thermal printhead is shown in Fig. 4. The substrate of the thermal printhead is glass, and the micro heater therein was formed in the screen printing process. The wiring for supplying power to the micro heater was also formed in the same process.

At first, we attempted to increase the transparency of the thermal printhead. In practice, the substrate of the thermal printhead is transparent glass and the overcoat of the wirings is translucent glass, however the internal micro heater and the wirings are opaque. The material of the internal heater was changed to translucent glass. The thermal printhead for enhanced transparency of the internal sections was newly manufactured just for contact surface observation. The optical transmittance of the thermal printhead produced in this way was 47.5% at a wavelength of 650 nm. However, we failed to observe the contact surface due to the short optical transmittance as described in section 2.1. The observation of the thermal printhead in detail revealed that the overcoat layer contained fine bubbles and additives which caused the laser beam to be scattered and not reach the contact surface. Thus, the contact surface of the thermal printhead needed to be observed by a different method which will be described in the next session.

To improve the heat transfer characteristics, four types of thermal prinheads with different internal structures and surface shapes were prepared. Sample 1 had one layer of the micro heater coated with an overcoat. In sample 2, the micro heater was coated twice with overcoat to reduce the dent near the micro heater segment. Sample 3 contained a two-layer micro heater. Sample 4 had two layers of both micro heater and overcoat. Table 2 shows the number of layers
of both micro heaters and overcoats for each sample, and the schematic diagram of the thermal printhead is shown in Fig. 4.

The surface profiles of the thermal printheads were measured with a scanning confocal laser microscope (OLS3100, Olympus) with the 50× objective lens (NA = 0.95). Since the field of view of the laser microscope is 256 × 192 µm versus the length of the thermal printhead of 16 mm, 3D measurements must be repeated 63 times and resulting profiles stitched together. Figure 5 shows the measured surface profiles. The dent depth of the heater portion corresponding to 7 - 10 mm along the abscissa with respect to the plateau corresponding to 12 - 14 mm is deepest in Sample 1, followed by Sample 2, Sample 3 and Sample 4. By over-coating twice, the unevenness of the wiring portion corresponding to 2-7 mm is considerably improved. However, it was difficult to flatten the dent of the micro heater simply by overcoating. To effectively achieve this, it was necessary to make the micro heater two-layered. On the other hand, the dent between the micro heater and the right wiring part, corresponding to 10-11 mm, remained.

### 2.3 Ultra-high transparent silicone rubber (UHTSR)

Since the contact surface of the thermal printhead was not able to be observed through the specially designed thermal printhead, we attempted measurements through the opposite side. As mentioned in section 2.1, glass is often used as a transparent material for observe contact surfaces (Nitta et al., 2011, Nitta et al., 2013). Recently, a study of contact surface observation using ultra-high transparent silicone rubber, UHTSR, was reported (Tsukiyama et al., 2015, Masuda et al., 2017). UHTSR has the same degree of transparency as glass (transmittance of 90% or more) and excellent flexibility. We used UHTSR instead of the transfer belt to observe the real contact portions.

The shore hardnesses of the UHTSR used in this study were A25, A40, and A70 according to JIS K 6235. As a guideline for the hardness number, A25 corresponds to a tire tube of a bicycle, the A40 to a plastic eraser, and A70 to a ball of baseball. Compared to the polyimide (PI) transfer belt material, the hardness of UHTSR is 1/500th. Hence, polyvinyl chloride (PVC) and polyethylene terephthalate (PET) film, which are transparent and harder than UHTSR, were also prepared.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Overview of thermal printheads with different number of overcoat layers and micro heaters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overcoat</td>
<td>Micro heater</td>
</tr>
<tr>
<td>Sample 1</td>
<td>1</td>
</tr>
<tr>
<td>Sample 2</td>
<td>2</td>
</tr>
<tr>
<td>Sample 3</td>
<td>1</td>
</tr>
<tr>
<td>Sample 4</td>
<td>2</td>
</tr>
</tbody>
</table>

![Fig. 4](image1.png) Structure of thermal printhead

![Fig. 5](image2.png) Profile curve of thermal printhead surface measured with a scanning confocal laser microscope.
3. Contact surface observation of four thermal printhead shapes

3.1 Observation using ultra-high transparent silicone rubber (UHTSR)

Figure 6 shows a method of observing the contact surface using ultra-high transparent silicone rubber (UHTSR). The UHTSR measuring 15 mm × 10 mm was pressed against a long thermal printhead of 16 mm in width. A glass plate was placed on the back of the UHTSR to bear the normal load. At the contact interface between the UHTSR and the glass plate, plant oil with refractive index 1.5 the same as the glass plate was applied to eliminate the effects of refraction at the contact interface. Although the refractive index of UHTSR is unknown, since the refractive index of silicone rubber is 1.40 to 1.43 in the literature, the refractive index of UHTSR is considered to be of that range. A normal load of 0.25 MPa was applied, which corresponds to the average normal pressure of the actual indirect thermal transfer printer. Under such conditions, a range of 10 mm × 4 mm of the contact surface was observed with the wide-field laser microscope.

The acquired images of the contact surfaces are shown in Fig.7 together with the cross-section of the thermal printhead. The real contact portion was dark due to the zeroth order interference, destructive interference, and the details of the images were difficult to see. Hence, the brightness of the image was raised about 40%. The UHTSR with hardness A25 was in contact with the entire surface of the thermal printhead as shown in Fig.7 (a). The central part of the image is the heater section, and while there is a fine irregularity on the surface, real contact is present everywhere. The upper part of the image is the wiring section with the five dents of about 10μm in depth in line with a constant spacing. Even in these sections real contact occurs over the entire surface. The A40 UHTSR as shown in Fig.7 (b) has a similar contact state as A25. For A70 shown in Fig.7 (c), a region not in contact over the large undulation of the wiring is observed. In other sections, intimate contact results as for A25 and A40. The small white spots seen in places are regions where air is left behind and voids are formed.

As described above, by simply pressing the thermal printhead against the UHTSR, the soft and sticky UHTSR follows the shape of the thermal printhead, resulting in full contact. Such full contact is caused not only by the soft UHTSR surface, but it also appeared that the surface of UHTSR is slightly moist affecting the adhesion property particular to rubber which is attracted by intermolecular force around the contact point. In order to evaluate the contact situation on a scale below the uneven spacing (several μm) of the thermal printhead, it is necessary to increase the hardness of the transparent body so that the UHTSR does not stick to the thermal printhead too much when the normal load is applied.

The adopted countermeasure is described in the next section.

3.2 Method to combine ultra-high transparent silicone rubber (UHTSR) and transparent polymer thin films

It was proposed that the effect introduced by the surface softness and the adhesion of the rubber could be improved by sandwiching a transparent polymer film with higher surface hardness between the thermal printhead and the ultra-high transparent silicone rubber (UHTSR). Polyvinyl chloride (PVC) with a thickness of 0.2 mm and polyethylene terephthalate (PET) with a thickness of 0.09 mm were used for this role. Table 3 and Fig. 8 show the hardness of UHTSR, PVC film, and PET film measured by a nano-indentation test with a nano-indenter (ENT-1100b, ELIONIX) at a normal load of 5 or 100 mN. It was seen that the PVC and PET films are harder than the UHTSR.

Figure 9 (a) shows the contact surface when sandwiching the PVC film to the contact interface. In the upper part of the image corresponding to the wiring portion, the regions of non-contact area are clearly visible in the recess between wires where the brightness is not completely dark. In the center of the image corresponding to the micro heater, the small black areas of intimate contact are mixed with small grey areas of non-contact. The region within the red square is shown enlarged. The black portions caused by the destructive interference show the real contact area and the white portions correspond to non-contact. Thin closed curves are visible within the white portions. In some cases, the small black spots are seen in the center of the closed curves, which will be explained later.

Figure 9 (b) shows the contact surface when the PET film was sandwiched. Compared with the PVC film in Fig.9 (a), the white portions of non-contact area are spread out. This is because the PET film is 18 times harder than the PVC film. Many interference fringes are observed since the gaps occur in many sections between the thermal printhead and
the PET film. Hence, obstruction from the interference fringe makes it difficult to identify the real contact area.

To validate the contact patterns in Fig. 9(a), we compare it with the 3-dimensional surface profile of the thermal printhead. Figure 10 (a) shows the difference in contact pattern of the thermal printhead to Fig. 9 (a) when using PVC film. Figure 10(b) shows the 3-dimensional surface profile of the thermal printhead at exactly the same position as Fig. 10(a). A part of Fig. 10(a) is enlarged in Fig. 10(c) and the same location in Fig. 10(c) is also enlarged in Fig. 10(d).
Table 3  Measurement result of hardness of each materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>Thickness, µm</th>
<th>Indentation load, mN</th>
<th>Maximum indentation depth, µm</th>
<th>Hardness, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHTSR, A25</td>
<td>1000</td>
<td>5</td>
<td>43.0</td>
<td>0.153</td>
</tr>
<tr>
<td>UHTSR, A40</td>
<td>1000</td>
<td>5</td>
<td>32.6</td>
<td>0.303</td>
</tr>
<tr>
<td>UHTSR, A70</td>
<td>2000</td>
<td>5</td>
<td>13.7</td>
<td>1.84</td>
</tr>
<tr>
<td>PVC film</td>
<td>200</td>
<td>100</td>
<td>17.8</td>
<td>15.8</td>
</tr>
<tr>
<td>PET film</td>
<td>90</td>
<td>100</td>
<td>5.7</td>
<td>287</td>
</tr>
<tr>
<td>Belt (PI film)</td>
<td>100</td>
<td>100</td>
<td>3.4</td>
<td>592</td>
</tr>
</tbody>
</table>

Fig. 8  Comparison of hardness of each material. A25, A40 A70 are ultra-high transparent silicone rubber. PVC and PET are transparent plastic film. PI is the transfer belt which used in practice.

Fig. 9  Observed images between thermal printhead and transparent plastic film: (a) PVC film, (b) PET film.
The surface height of this region is found in the range of 0-2μm from Fig. 10(d). Figure 10(e) shows the superposition of Figs. 10(c) and 10(d). It is clear that the higher regions (warm colors) correspond to the real contact area (black) and the lower regions (cold) to the non-contact area. Small gaps between the contact surfaces lead to the closed contour curves. These situations are graphically explained in Fig. 11. The black filled regions are the real contact regions and the contour curves are the interference fringes of laser light created by the gaps between the two surfaces. The laser wavelength λ of the wide-field laser microscope is 650 nm, and the interference fringes appear at positions where the clearance is $\lambda/2$, 325 nm. The small black spot appearing at the center of the contour line in Fig. 11(a) is the

![Fig. 10 Comparison of observed images and surface profiles](image)

Fig. 10  Comparison of observed images and surface profiles : (a) overall view of observed image, (b) overall view of surface profiles, (c) magnification of (a), (d) magnification of (b), (e) superposition of (c) and (d).

![Fig. 11 Explanation of interference fringe](image)

Fig. 11  Explanation of interference fringe : region filled in black shows real contact area contour curves are interference fringes.
second-order fringe, corresponding to an increase in clearance to 650 nm.

The purpose of this study is not to seek the exact amount of real contact area, but to establish the experimental method of visualizing the real contact pattern for evaluating the validity of contact analysis by FEM. Hence, we will focus on the PVC film which clearly shows the distribution of real contact area. Although the real contact area will be somewhat overestimated with the PVC film, visualization of real contact area corresponding to changes in clearance of 1 μm or less are seen as in Fig. 10 (e), and for verification of FEM analysis the experimental accuracy is considered to be sufficient.

3.3 Transformation from distribution of real contact area into real contact ratio

The interference fringes generated in the clearance were obstacles towards identifying the real contact pattern from the acquired image. Hence, we raised the gain of the photomultiplier of the wide-field laser microscope so that the line width of the interference fringes became relatively thin and disappeared in the observation image. Thereafter, by binarization of the image, the real contact pattern without interference fringes was obtained as shown in Fig. 12(b). The threshold value was determined as 150 by visual observation so that almost all contact points maintain the same shape before and after the threshold process. As mentioned above, the purpose of obtaining the real contact pattern is to examine the validity of the 2-dimensional FEM contact analysis. However, Fig. 12(b) represents the 3-dimensional contact distribution, which is difficult to directly compare with the 2-dimensional FEM analysis. Therefore, the number of black contact pixels was integrated in the vertical direction, and indicated as a real contact ratio of each row like a histogram. The definition of the real contact ratio is as follows.

Real contact ratio [%] = (number of black pixels / total pixel number of 8000 in a vertical line) × 100

Comparing Fig. 12(c) with Fig. 12(b), it is found there was barely any intimate contact as the ratio of black pixels was lower. In the wiring portion of Fig. 12 (c), the surface height is about 10 μm and only the ridges of the thermal print head make contact with the PVC film. In the nip, regions where the black pixel ratio is lower than 10% are indicated by a red dashed circle. This is due to the inclination of the thermal printhead surface abruptly changing and the PVC film not following it. In other areas the black pixel ratio remained at only 20 to 40% since the surface roughness of the thermal print head prevented intimate contact. An improvement to the contact ratio can be expected by reducing the
3.4 Distribution of real contact area for each thermal printhead

The real contact ratios over the nip region where heat is transferred from the thermal printhead to the transfer belt are shown in Fig. 13, together with the acquired images of the contact surfaces. The horizontal axis represents the

surface roughness of the thermal printhead by polishing after the overcoat process.
distance from the nip center. By comparing the two graphs of the real contact ratio and the contact image, it is possible to determine the portions where real contact is unlikely to occur around the micro heater of the thermal printhead.

In Sample 1, the real contact ratio remained between approximately 20% and 40%. Since the nip is an important area of heat transfer, the higher real contact ratio is suited for improving heat transfer performance. The average value of the real contact ratio in the nip region of each sample was determined as 27.3% for Sample 1, 30.1% for Sample 2, 22.3% for Sample 3 and 33.7% for Sample 4. Compared to Sample 1 and Sample 3, Sample 2 and Sample 4 have larger real contact ratios because they have two layers of overcoats that make the inclination of the dent gentler than one layer. However, production cost is increased by the two layers of overcoats. In addition, it is also feared that temperature response decreases as the micro heater and the contact surface are separated by two layers. A high temperature response is considered necessary for examination by thermal conductivity analysis (FEM).

4. Discussion (2-dimensional FEM analysis in comparison with the experiments)

To compare the real contact ratio obtained with the wide-field laser microscope, 2-dimensional contact analysis was performed using FEM code, Marc 2013.1, MSC software. An overview of the analysis model is demonstrated in Fig. 14. The transfer belt was located on the underside of the thermal printhead. This transfer belt is a 3-layer structure consisting of PI (thickness 50μm), silicone rubber (thickness 50μm) and PTFE (thickness 10μm) from top to bottom. PI was used to improve heat resistance because the upper layer makes contacts with the thermal printhead at high temperature. The second layer of silicone rubber has a cushioning property at low Young's modulus and the bottom PTFE provides releasability and lubricity. A platen roller of an outer diameter of 29 mm was placed under the transfer belt, and inside the platen roller a steel shaft of a diameter of 15 mm was inserted. In this analysis, the printing material was omitted.

The thermal printhead and the platen roller shaft were treated as a rigid body, and other parts as an elastic body. The material properties of each elastic body are shown in Table 4. Generally, elastic modulus of elastomer can’t be simply defined as a constant, but an elastic modulus is given to each elastomer since nonlinearity of the elastomer makes calculations complicated. The FEM model was created in 2-dimensions under a planar strain state and assumption of 320 mm depth. The thermal printhead was completely fixed and a load of 400 N was added to the platen shaft.

The analysis result of the thermal printhead of Sample 1 is shown in Fig. 15. In some places, it can be seen that there is a slight clearance between the thermal printhead and the transfer belt shown by the area filled in red. The size of this clearance was considered to be related to the real contact ratio of the thermal printhead. Hence, the histogram of the real contact ratio shown in Fig. 13 and the size of the clearance examined by the analysis shown in Fig. 14 are compared in Fig. 16. The solid line in Fig. 16 represents the experimental result, and the dashed line is the simulation result. In Sample 1, the clearance of the simulation is correspondingly large where the real contact ratio of the experimental value decreases to about 5% or less, shown in shaded regions. However, the clearance of the simulation does not increase much in the vicinity of 1.8 mm along the horizontal axis. The same tendency of Sample 1 is also seen in Sample 3.

Since Sample 2 and Sample 4 have double overcoat layers, the surface shape of the thermal printhead is relatively
flat, which is advantageous compared to Sample 1 and Sample 3 for intimate contact. In the simulation, there are very few regions with significant clearance. In Sample 2, at the abscissa of approximately 1.2 mm there is a discrepancy where the real contact ratio is decreasing in the experiment but the clearance of the simulation does not increase much. There are a few reasons for this. One of them is that the shape of the thermal printhead is not uniform in 3-dimensions and that the cross-sectional shape referred to in the 2-dimensional simulation happens to be a shallow dent. In the 2-dimensional FEM analysis, the clearance is uniform in the depth direction, but in the actual thermal printhead, the clearance is 3-dimensionally distributed. In this way, it is difficult for the boundary conditions to be perfectly matched in the analysis and the experiment. Therefore, since the experimental and analytical tendencies of contact being less likely to occur for a concave characteristic shape were the same, the first purpose of this research was fulfilled.

Fig. 15 Analytical clearance in the nip between thermal printhead and transfer belt.

Fig. 16 Comparison between observation and analysis results. The solid line shows the real contact ratio between thermal printhead and PVC film. The dashed line shows calculated clearance between thermal printhead and transfer belt.
From the above, it was confirmed that the position where the real contact ratio becomes smaller is almost same as the position where the gap becomes larger. Therefore, the real contact ratio obtained by the experiment can be used for verifying the numerical simulation result.

5. Conclusions

The final purpose of this study is to replace a conventional fixing roller with a small thermal printhead as a heat-saving technique for indirect thermal transfer processes. The thermal printhead used in the thermal transfer printer is expected to be able to contribute to its power saving. Since the thermal printhead is too hard to deform precisely with the mating surface, it is likely that gaps will occur between them through which heat is difficult to transfer. In a previous study, we conducted a contact analysis by finite element method to examine the effect of waviness on the contact surface, caused by the micro heater and the wiring in the thermal printhead. However, at the time there was no useful verification method for such FEM analysis. In this study, to clarify the real contact pattern of the thermal printhead visualization, a contact surface was developed using ultra-high transparent silicone rubber as the mating surface of the thermal printhead. As a result, the following results were obtained:

1) A method of observing the contact surface over a wide region of the thermal printhead using a wide-field laser microscope was developed. We succeeded in visualizing the real contact patterns by using ultra-high transparent silicone rubber and transparent plastic film.

2) We visualized the contact surfaces of four types of thermal printheads with different structures and surface shapes to determine which provided excellent contact characteristics.

3) When comparing the real contact patterns and the clearance between the thermal printhead and the transfer belt, positions of large clearance agree with decreases in real contact ratio. It was concluded that the FEM simulation can be validated through the visualization of real contact surface.

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