Surface Heating Fuser System for Laser Beam Printer

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Abstract

The surface heating fuser system which has low energy consumption and high heating up speed is introduced. The seamless heating tube is designed and fabricated by extrusion process with composite material of carbon nano tube and liquid silicone rubber. In order to minimize the heat capacity, a thin film layered heating material tube is selected. For interconnecting between heating material and electrical supply unit, electroplated nickel conductor and carbon brush are adopted. Numerical analysis is performed to predict the heat transfer characteristic of the fuser and its performance is tested and analyzed. The temperature control of the tube is the critical parameter so as to accomplish the fusing performance. The printing speed of the proposed fuser structure is up to 40ppm.

Introduction

The fusing process is the one of electro-photography process in laser beam printer and fixes the toner into the media by using heat and pressure. The key issues of fusing process are heating speed and energy consumption because most of energy consumption in printer lies in fusing system. As the energy regulation of EPA and Blue Angel on printer is getting tougher than ever, a necessity to reduce the energy consumption of fuser unit has become critical issue. Kimura designed first SURF (Surface Rapid Fusing) applied to small analog copier and achieved a shortest waiting time among the conventional fusing technology [1,2]. Uchida simplified and modified the SURF into ODF (On Demand Fusing) [3]. The ODF has expanded from entry level A4 printer to A3 copier. The simulation method and electrical driving circuit have been studied in order to optimize the structure and increase the fusing performance [4,5]. We introduce a new surface heating fuser technology using CNT (carbon nano tube))/LSR (liquid silicone rubber) composite material.

Surface Heating Fuser Structure

In order to increase the heating speed and decrease the energy consumption of a fuser, it is important to minimize the heat capacity of fuser. The heating material is fabricated into thin film type seamless tube so as to decrease the heat capacity and a supporting structure is inserted into a heating material tube. Pressure roller applies compressive force to the supporting structure and builds contact area called nip by deformation of the roller. Sponge or LSR material is adopted to pressure roller and the elasticity is carefully chosen to make a proper nip width. The electrical energy applied to the tube by way of electrode is formed on each end of tube. The electrical current generates heat by Joule heating of the heating material. The heating material consists of CNT and LSR where CNT dispersed in the LSR forms an electric path for Joule heating. The heat transferred to paper through the nip surface and mechanical pressure is applied to the paper when it passes through the pressure roller and the nip support structure. The nip support structure determines the shape of nip and support the pressure for fusing process. Figure.1 shows structure of the fuser system.

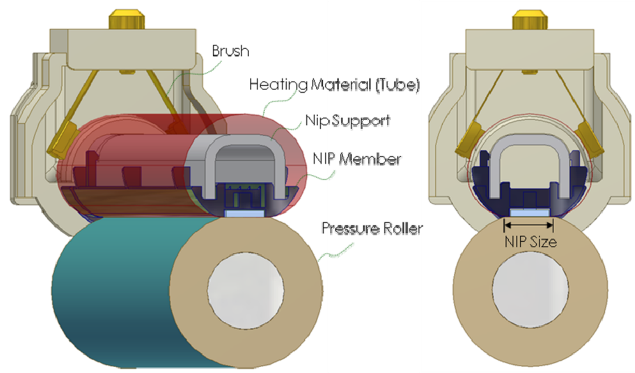

Figure 1. *Surface Heating Fuser System*

Heater and Electrode Structure

The surface heating fuser we suggested requires thin and deformable tube. The multi-wall CNT is selected as the heating material for its high conductivity and compounded with LSR material. The electrical conductivity of CNT/LSR composite material is determined by intrinsic conductivity and aspect ratio of CNT. Figure 2 shows the concept of CNT/LSR tube. Through the specific formulation process, the high electrical conductivity of the tube can be obtained more than 500 S/m.

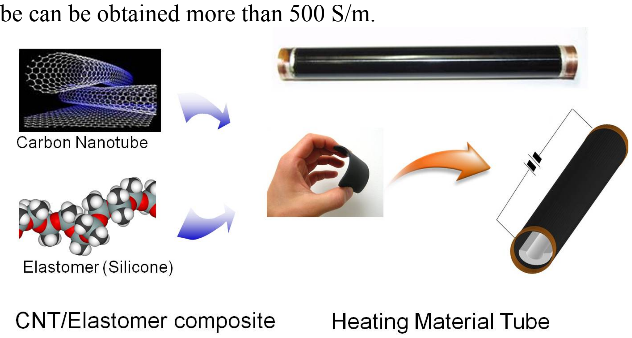

Figure 2. *CNT/LSR Heating Material Tube*

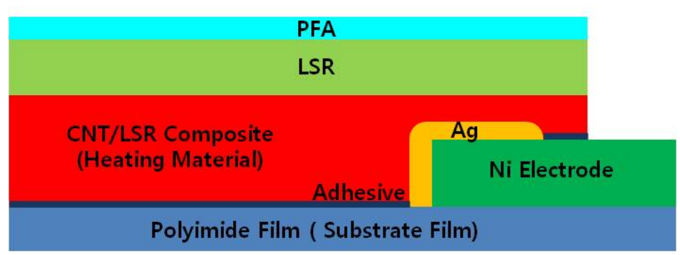

Figure 3. *Electrode Section of Heating Material Tube.*

The CNT/LSR heating material is flexible and can be fabricated to thin film tube having low heat capacity. Figure 3 shows the structure of electrode section of the tube. A Nickel electrode conducting the electrical current to the heating material is integrated at the both side of the fusing tube.

An adhesive between the nickel electrode and the CNT/LSR composite must have both good adhesion and electrical conductivity at the same time. In order to satisfy the requirement, we suggest the structure which divides electrical and mechanical inter-connection separately. Ag paste makes an electrical connection and a polymer adhesive at both ends of the Ag paste acts as a mechanical connection. In case of designing surface heating material, the coefficient of thermal expansion of each layer should be matched together to release the thermal stress between the adjacent layers. Thicknesses of each layer of polyimide substrate, nickel electrode, CNT/LSR composite, LSR, PFA are 30um, 40um, 300um, 180um, 30um, respectively. The nickel electrode is assembled to the polyimide substrate in advance and the CNT/LSR composite is extruded. LSR coated onto the CNT/LSR composite gives proper elasticity and thermal spreading, and PFA at the outmost layer is applied for easy release of paper.

The pressure roller is rotated by gear trains and the tube shaped heating material film is rotated by friction force between pressure roller and the tube. In order to prevent the slip of paper, the friction between nip member and the tube should be minimized and lubricant is necessary. Electrical power must be supplied after rotation of the CNT tube to prevent overheating. As Figure 4 shows, carbon brush is adopted for electrical supply apparatus because it has low friction against the nickel electrode with affordable cost.

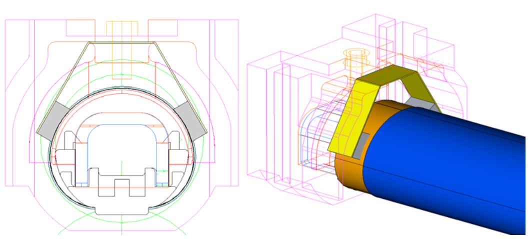

Figure 4. Carbon Brush of Surface Heating Fuser.

Numerical Simulation

The purpose of surface heating fuser structure is to increase the thermal efficiency and decrease the warm up time. Finite element model is applied to simulate the thermal conduction in fusing structure. Figure 5 shows the FE model and result of thermal analysis Diameter of the tube and the pressure roller is 18mm and 24mm respectively. Nip width is 10.7 mm and input power is 950W. If the fusing temperature is assumed to be 170°C, the time for warm up would be 4.5 seconds at the outer surface of the tube and 5.8 seconds at the nip. In a heat conducting analysis, 35% of the applied power is conducted to the pressure roller, 15% of the power is to nip member, 44% of the power is to the tube. The only 4% of the power is dissipated from the tube to ambient air. In order to increase heat efficiency, it is the key parameter to minimize the heat capacity of the tube.

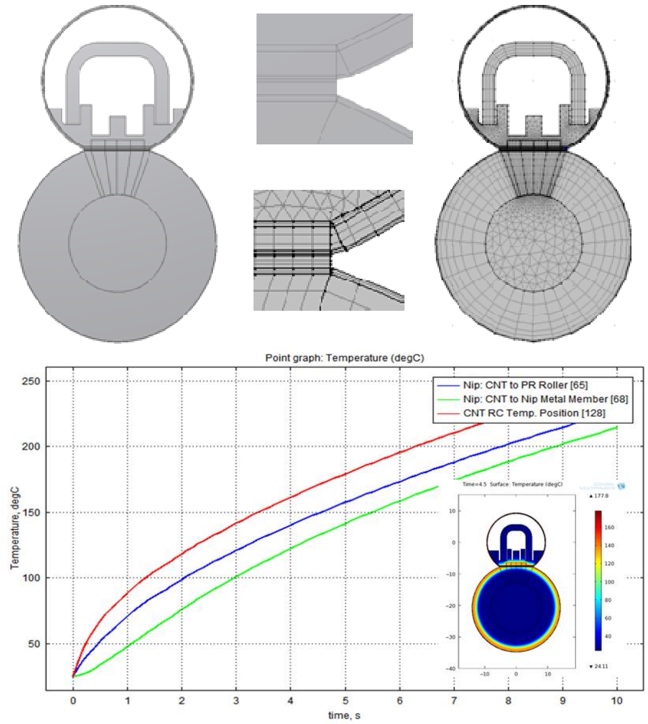

Figure 5. FE Model of Heat Transfer Simulation

Fabrication of Fuser Device

The proposed fusser system is fabricated and tested. Figure 6 shows the prototype device. Two thermistors measure the center and edge temperature of the CNT fuser. The fixing temperature of the fuser is controlled with the center temperature and the edge temperature is monitored to prevent overheating where paper is not passing through the uniformly heat generated fuser. In order to deform the pressure roller and obtain the nip area, the pressure roller compressed against the nip member at 9kgf force. A bush inside the nickel electrode supports and guides rotation of the tube. The heating belt deforms the circular shape of cross section so as to form a nip area. The optimum shape of deformation can be designed by calculation. Deformation energy of the tube from original circular shape to truncated oval shape is minimized by the frame of the bush as the pressure between the roller and nip member increases.

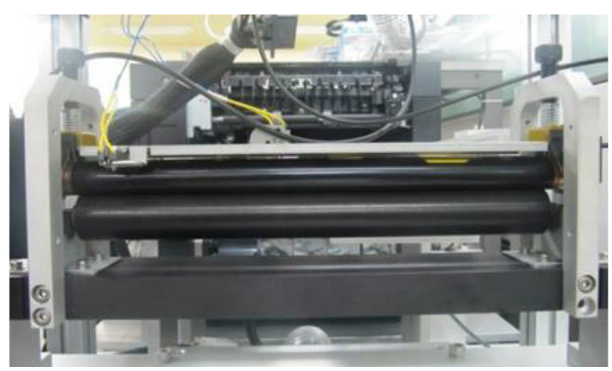

Figure 6. Prototype of Surface Heating Fusing Device

Fusing Performance

The CNT tube generates heat at the surface of the tube and transfers heat directly to a paper without any structure in-between them. The temperature uniformity of heating tube is the key performance factor to accomplish fusing performance because temperature variation influences the fusing process due to low heat capacity of the fuser. Figure 7 shows the results of temperature distribution of the tube. Thermal image is captured by IR Camera during warming up and maintaining the fusing temperature. The upper side objet is the tube and the lower side object is the pressure roller. The variation of temperature in longitudinal direction is measured under ±4°C and the variation in circumferential direction is under ±7°C. The fluctuation of temperature in heating tube is due to a variation of thickness and electrical conductivity of the tube. Eccentricity between polyimide substrate tube and an extrusion die during the extrusion process of the CNT/LSR composite results in circumferential thickness variation. When the heating tube rotates during fusing process, the periodic ripple of temperature can be observed due to the thickness variation as in Figure 7. The thickness variation in longitudinal direction results from the mechanical movement error of the heating tube fixture in extrusion process. As the surface heating tube has a low heat capacity and thermal conductivity, the temperature difference in the tube results in the fixing performance variation in the printing media. Therefore, design and control of the extrusion process to meet the thickness specification of the tube is critical. The maximum temperature in heating tube occurs in edge side of the tube because of thermal non-equilibrium in paper non-contact region. The generated heat in the region accumulates because the tube has low heat conductivity in longitudinal direction.

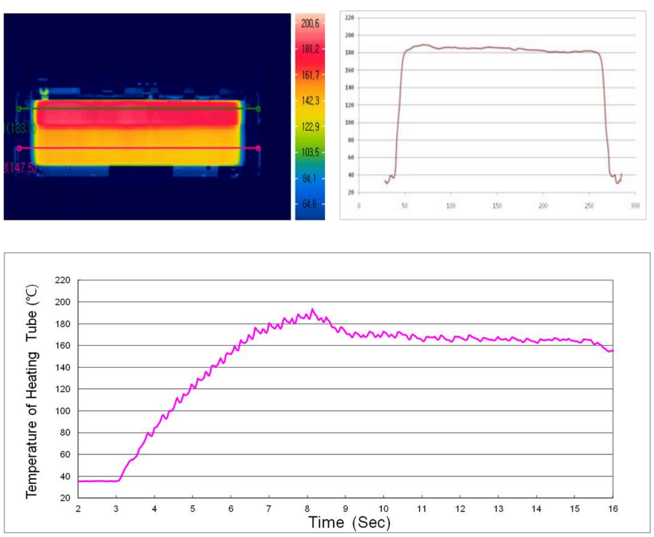

Figure 7. *Temperature Distribution in Surface Heating Tube*

We added a metal strip at the nip member to secure longitudinal heat transfer area from paper non-contact region to center part of the tube. This metal strip, however, did not show any noticeable effect because of the large thermal resistance between the heat generating layer and the metal strip.

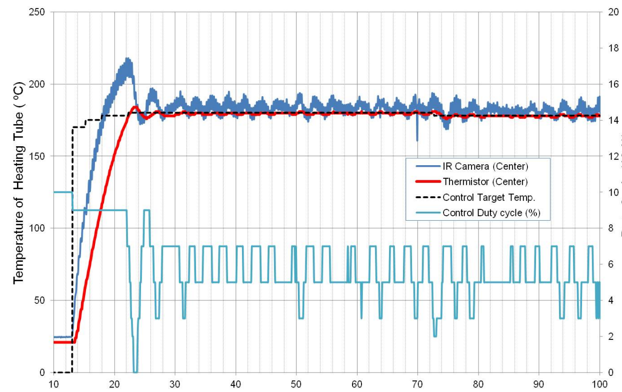

Figure 8. *Temperature Profile during Fusing Process*

Due to the low heat capacity of heating tube, temperature of the tube is easily affected by ambient situation and so it is a technical challenge to control and maintain the temperature of fusing system. In order to implement a temperature control system, the thermistor is applied to the temperature sensor. The low cost thermistor has a time response more than 2 seconds. But the warming up and cooling down speed of the surface heating tube is more than 35°C/sec, the slow sensing response is a hurdle of fuser control. In Figure 8, result of duty control for the thermally light fusing system is presented. The measured temperature by thermistor shows the accurate results for target temperature. On the other hand the measured temperature by IR camera shows the temperature ripple in warming up process and the maximum temperature of the tube rises up to 220°C. The reason why this difference between the two measured temperatures happens is the slow response of thermistor. This results show that conventional temperature sensor and control method are not enough for the proposed surface heating material fuser. In case of fixing performance, even though there is a small area in lower temperature than the fixing temperature, the fixing performance in paper is not qualified because the heat is not spread inside the tube for its low longitudinal heat conductivity. The thickness uniformity of heating material and the accurate temperature control are indispensable for the obtaining the fixing performance in surface heating fuser. The TEC (Typical Energy Consumption) is measured for 1.2kWh.

Electrode and Electrical Supply unit

Contact resistance between the electrode and the carbon brush is key design factor for the electrical supply unit. This factor can be controlled by the contact force of the carbon brush and the material properties of the electrode and the brush. In order to analyze the effect of parameters, experimental apparatus is integrated as shown in Figure 9. The applied electrical current for electrode and brush is 5A. This value is assumed for the case when the fuser of 40ppm printer consumes the power of 1100W at 220V. A dummy load (5Ω) is attached on behalf of the CNT/LSR heating material to minimize the deference between dummy load and contact resistance. This circuit can measure the voltage drop between carbon brush and electrode and the real contact resistance could be obtained. As the electrode contact force increases, mechanical wear increases and electrical wear decreases, the optimum electrode contact force range exists [6]. Figure 9 shows the measurement results. The contact resistance has minimum value 0.2Ω at the range of electrode contact force; 40gf to 80gf. Temperature is another parameter to consider. The carbon brush is composite material of carbon and copper. As temperature rises high, copper gets oxidized and bonding with carbon gets weakened, carbon breaks into particles and forms a carbon film on the contact surface of electrode. The contact resistance gets high because the carbon film has low density and oxidized at high temperature. As shown in Figure 9, the contact resistance increases sharply at more than 200 °C. The operating temperature of the fuser with carbon brush should be maintained under the 200°C so as to prevent Joule heating at brush contact region in nickel electrode.

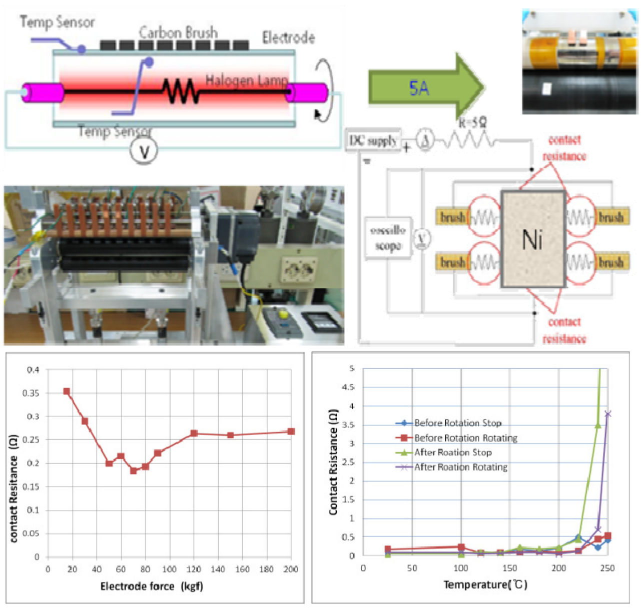

Figure 9. *Experimental Apparatus and results for Contact Resistance*

Conclusion

The surface heating fuser system has been developed and verified for fast and efficient fusing. The heating layer is made up of composite material of carbon nano tube and liquid silicone rubber. The nickel electrode attached to the CNT/LSR composite with adhesives contacted with the carbon brush, and provided electric power from the electric supply unit. Due to the low thermal capacity of the CNT tube, fast warming speed and efficient energy consumption is achieved. The thickness uniformity of heating materials and the temperature control of fuser are the key factors for obtaining stable fixing performance and assuring thermal reliability.

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Author Biography

Oh Hyun Baek received the B.S. and M.S. degrees in mechanical engineering from Korea University, Seoul, Korea, in 1991 and 1993,, respectively. He joined Samsung Electronics Co, Ltd. Suwon Korea, and he worked on research and study of ink jet and Laser Beam printing process at the Digital Media Communication R&D Center. His recent research topic is focused on fusing technology.