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Inkjet Printing of Biomedical Adhesives

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ABSTRACT

Synthetic adhesives have largely displaced natural adhesives in the automotive, aerospace, biomedical, electronic, and marine equipment industries over the past century. We have demonstrated the thin film deposition of biological adhesives using piezoelectric inkjet technology. A MEMS based piezoelectric actuator was controlled to jet uniform fluid flow of the adhesive solution through the ink jet nozzles. Microscopic deposition of adhesives enables improved bonding for a range of advanced electronic and biomedical applications. By printing such small and spatially aligned drops, bond lines between materials are reduced, ultimately resulting in increased bond strength and structural integrity. Piezoelectric ink jet deposition of biological adhesives may greatly improve wound repair in next generation eye repair, fracture fixation, organ fixation, and wound closure.

INTRODUCTION

Ink-jet technology is non-contact printing process for processing materials [1, 2]. In thermal printing, a resistive element is used to heat the fluid, creating a bubble that forces the ink out of the nozzle. A similar process has been utilized for printing biomolecules such as proteins and various living cells [3-5]. However, the thermal stimulus does not entirely preclude damage to sensitive biological materials. Athermal ink-jet printing technologies, including syringe-solenoid and piezoelectric systems, have also been developed [6]. In a solenoid system, a syringe pump is used with a microsolenoid actuator to create controlled fluid flow across an orifice. However, high internal pressures can result in damage to the printer head. In a piezoelectric inkjet system, piezoelectric crystals are used to create mechanical vibrations to control fluid flow via the nozzle by the application of external voltage. Piezoelectric printers are categorized based on the deformation mode such as squeeze, bend, push and shear modes in the piezoelectric crystal [7]. The general principle of operation involves the creation of a rapidly moving stream of fluid that passes through a small nozzle. When a given linear velocity is reached by the fluid, it is ejected from the orifice as a droplet. Resolution of the printed features are dependent on several parameters, including fluid viscosity, surface tension, fluid-mass velocity, nozzle size, droplet size, and lateral resolution of the printer head. In this study, piezoelectric actuated ink-jet technology was used to develop CAD/CAM microscale patterns of biomedical adhesives.

EXPERIMENTAL DETAILS

Vetbond™ tissue adhesive (n-butyl cyanoacrylate) (Fisher Science, NJ, USA) and Nexaband™ tissue adhesive (2-octyl cyanoacrylate) (Fisher Science, NJ, USA) were stored in the cartridge at a temperature of 28 °C. A piezoelectric inkjet printer (Dimatix Inc., CA, USA) was used to dispense picoliter quantities of adhesives in a predefined pattern. The MEMS-based cartridge of the inkjet printer was equipped with 16 nozzles with 21 µm diameter and 254 µm spacing. The adhesive monomer solution was purged out and calibrated for constant front-velocity for all nozzles prior to deposition. The time of flight of the drop (~10 picoliter each) was recorded using an ultra-fast camera equipped with the inkjet system. Resins were deposited at 10-40 V using an optimized wave-form into various CAD/CAM patterns on silicon, agarose gel, and KCl substrates and subsequently imaged.

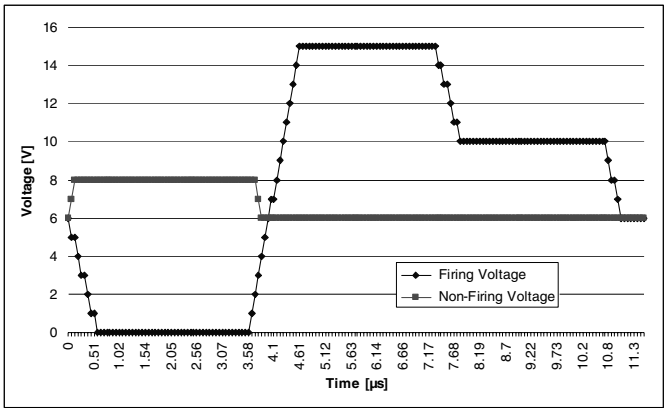

Figure 1. A sample voltage waveform used for jetting adhesives

Drop-cast samples were prepared to compare the absorption peaks to the ink jet processed adhesive. Fourier transform infrared spectroscopy (FTIR) was performed using a Mattson 5000 series (Madison Instruments, WI, USA) spectrometer with 4 cm^{-1} resolution. The absorption spectra (4000 – 500 cm^{-1}) was recorded for the ink-jet deposited and drop-cast adhesives. Optical imaging of the deposited adhesives was performed using a Leica DLMB upright microscope (Leica Microsystems, IL, USA).

RESULTS AND DISCUSSION

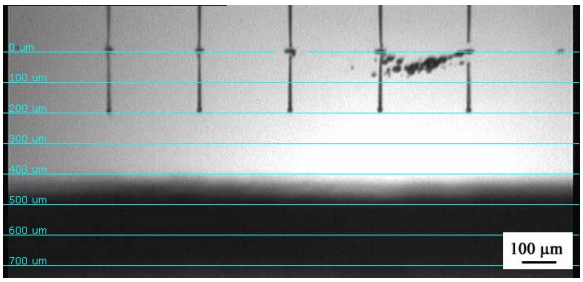

Figure 2. Optical micrograph of cyanoacrylate adhesive monomer release from five 21 µm nozzles at 30 µs.

Figure 2 contains an image of the calibrated adhesive drops from five nozzles traveling a distance of 200 µm in 30 µs. Figure 3 shows the travel of the adhesive drop in response to increasing voltages (10-40 V). An increase in voltage led to an increase in mass-velocity, recorded at 30 µs. The graph shows a linear increase in front-velocity with voltage.

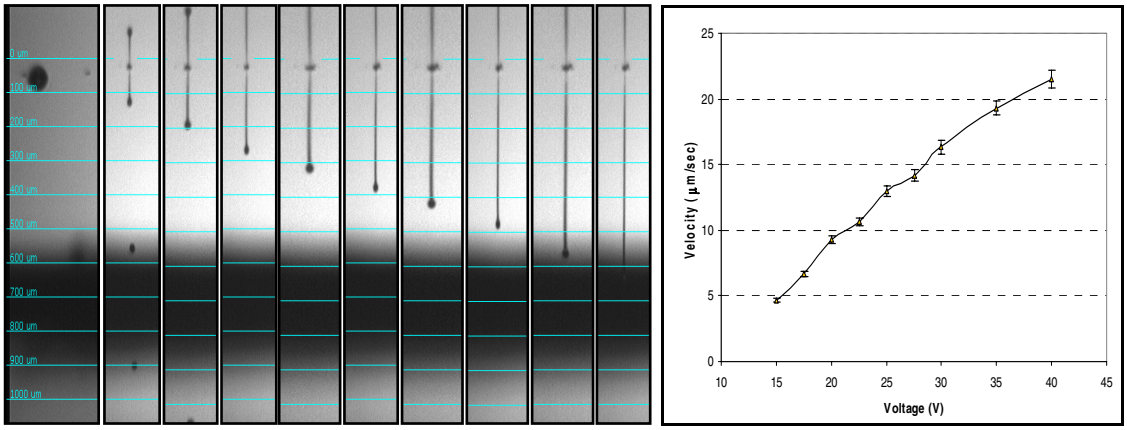

Figure 3. Adhesive drop images recorded at 30 µs delay, showing distance traveled by cyanoacrylate drop with increasing voltage peaks (left to right). Graph shows the frontal velocity (µm/s) vs. voltage (V) for the images (left to right).

Figure 4 contains optical micrographs of n-butyl cyanoacrylate patterns on silicon substrates. Bond-lines of approximately 100 µm can be observed. Figure 5 contains optical micrographs of 2-octyl cyanoacrylate microarray patterns on 1% agarose gel. Patterns exhibiting ~20 µm features were observed.

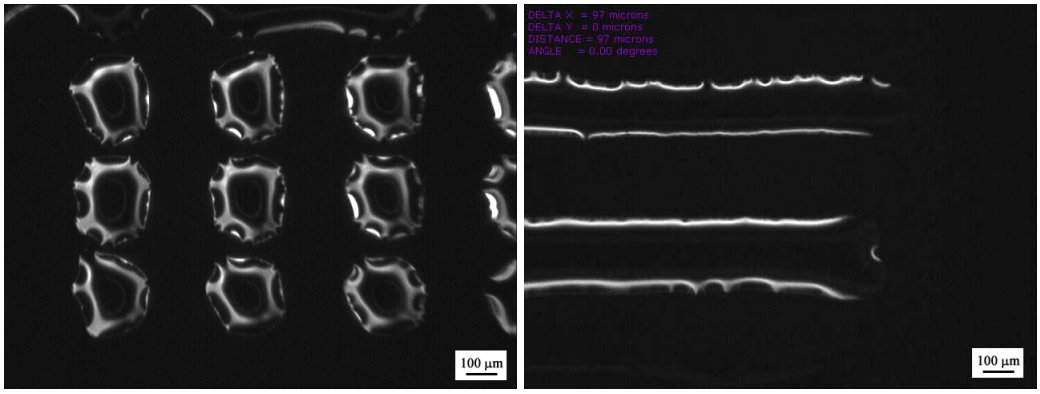

Figure 4. Optical micrograph of n-butyl cyanoacrylate patterns on silicon substrates.

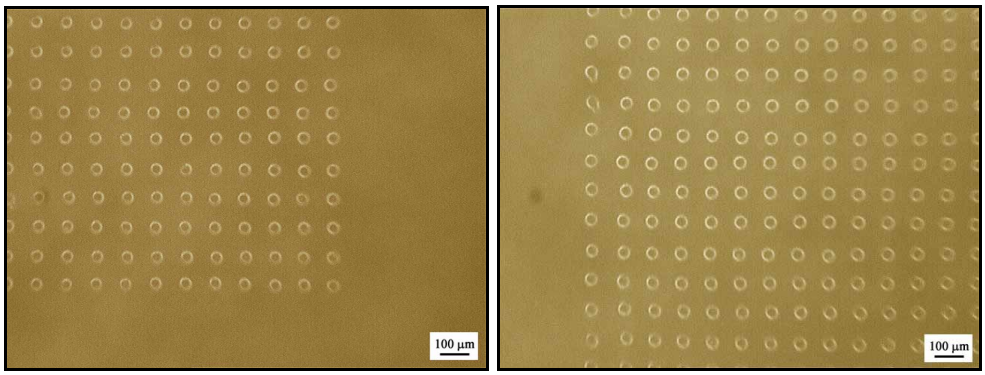

Figure 5. Optical micrograph of 2-octyl cyanoacrylate microarray patterns on 1% agarose gel.

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Fourier transform infrared absorption spectra overlay of ink-jet deposited and drop-cast n-butyl cyanoacrylate adhesive (Figure 6) and 2-octyl cyanoacrylate adhesive (Figure 7) demonstrate the presence of relevant structures. Microscopic deposition of adhesives enables improved bonding for a range of advanced biomedical applications. Controlled dispensing of picoliter quantities of adhesives allows for a reduction in bond lines between materials and improved performance.

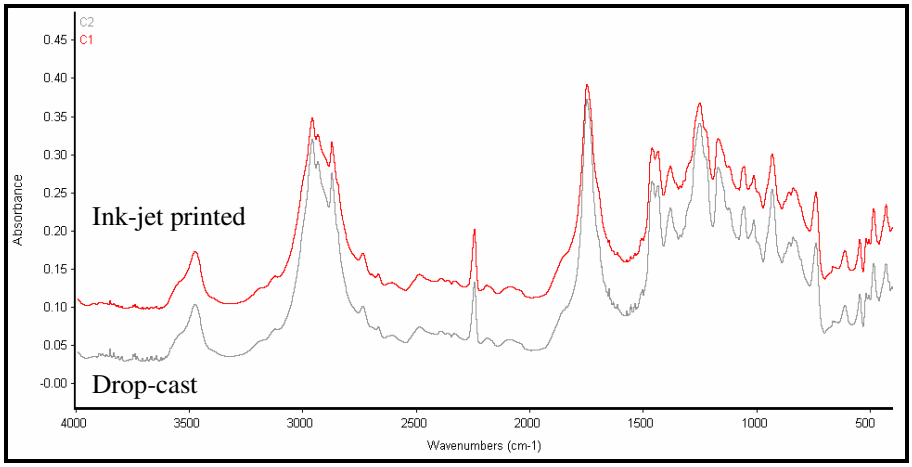

Figure 6. Fourier transform infrared absorption spectra overlay of ink-jet deposited and dropcast n-butyl cyanoacrylate adhesive.

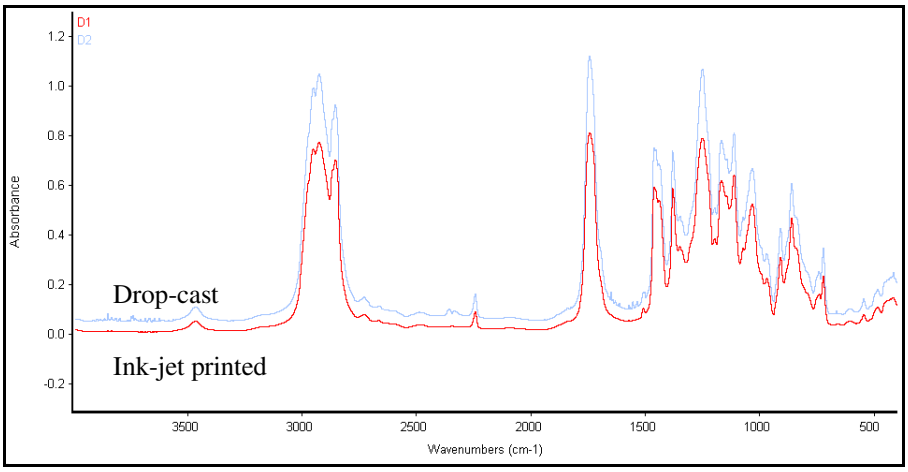

Figure 7. Fourier transform infrared absorption spectra overlay of ink-jet deposited and dropcast 2-octyl cyanoacrylate adhesive.

CONCLUSIONS

We have demonstrated piezoelectric inkjet deposition is a powerful, non-contact and non-destructive technique for rapid prototyping of biological adhesives for clinical applications. Piezoelectric ink jet deposition of biological adhesives may greatly improve wound repair in next generation eye repair, fracture fixation, organ fixation, and wound closure devices.

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