Cutting edge technology: sound sharpens the blade

Craig Stuart Carlson, Antje Pohl, David Keir, Michiel Postema

CUTTING EDGE TECHNOLOGY: SOUND SHARPENS THE BLADE

Craig S. Carlson[a], Antje Pohl[b], David G. Keir[c], Michiel Postema[a,*]

[a] *School of Electrical and Information Engineering, University of the Witwatersrand, Johannesburg, 1 Jan Smuts Laan, Braamfontein 2000, South Africa.*
[b] *Institute of Integrated Systems, Ruhr-University Bochum, Universitätsstraße 150, 44801 Bochum, Germany.*
[c] *Department of Engineering, University of Hull, Cottingham Road, Kingston upon Hull HU6 7RX, United Kingdom.*

Abstract

Constantly sharp knives have applications in industrial cutting, clean shaving, and precision surgery. With the purpose of increasing blade sharpness, an ultrasonic knife was built, operating at 134-kHz continuous ultrasound with an average temperature increase of 0.4 °C at the blade. The sharpness of the incisions made to a sheet of plain printer paper with a blunted blade under sonication were compared to those of the same blade without sonication and to industrially cut paper edges. The incisions from the sonicated blade were visibly sharper than those from the unsonicated blade, and at least as sharp as those from the industrially cut paper edge.

Keywords: B#, Blade, incision tortuosity, precision cutting, sharpening, sonication, ultrasonic knife.

1. INTRODUCTION

Blades lose their sharpness over time with every cut or shaving stroke made. Research on cutting technology focusses on blade materials and physical sharpening tools. Ultrasound is commonly used in cleaning and sterilising cutting equipment [1]. The role of sonication on cutting performance has previously been investigated with a focus on the processing of food [2, 3, 4] and wood [5]. These investigations utilise an application-specific transducer and blade construction. The use of ultrasonic cutting has also been investigated in the support of surgeries [6, 7, 8]. However, the key consideration in these investigations was the effect of temperature where a lower temperature rise resulted in less tissue damage.

To this purpose, a set-up was designed which allowed for the sonication of an interchangeable blade, whilst keeping the blade temperature consistent. The main applications of this technology are in industrial cutting, clean shaving, and precision surgery.

2. MATERIALS AND METHODS

As illustrated in Figure 1, an AFG 3021B arbitrary waveform generator (Tektronix Incorporated, Beaverton, Oregon, United States) was used to generate a continuous signal of 134 kHz with a 10-V peak-to-peak amplitude, which was fed into an A-150 55-dB linear power amplifier (ENI Technology, Inc., Rochester, New York, United States). This signal was converted to ultrasound using a custom-built, impedance matched, backed, single element ultrasound transducer that was constructed using a Pz37 piezoelectric disc (Ferroperm Piezoceramics A/S, Kvistgård, Denmark), with a Perspex casing surrounding the transducer. The Pz37 piezoelectric disc was chosen for its low acoustic impedance for improved acoustic matching.

A Perspex rod, serving as a waveguide, with a 6-mm diameter and a 55-mm length was attached to the 13-mm Perspex matching layer by means of a 1-mm diameter wire of 15-mm length. Perspex was used, as

*Correspondence to: michiel.postema@wits.ac.za

it has an acoustic impedance close to that of water. The total length of the matching layer and waveguide corresponded to a multiple of the transducer wavelength for maximum acoustic energy transfer to the blade.

With two screws, a Stainless Steel No. 11 Surgical Scalpel Blade (Swann-Morton Limited, Sheffield, United Kingdom) was attached to the Perspex rod, illustrated in Figure 2. The No. 11 surgical scalpel blade is used in surgeries such as ligament reconstruction [9], and laproscopic surgery [10]. It is also commonly used as a hobby knife blade, thus serving multiple purposes. The blade can be easily changed if a different cutting purpose is required. The blade was blunted by manual cutting and exposure.

The two input channels of a FLUKE 52II THERMOMETER (Fluke Corporation, Everett, Washington, United States) were physically connected to a position on the blade (T1) and to a position to the side of the piezoelectric element (T2), shown in Figure 3. Temperature measurements were taken every 30 seconds for 15 minutes.

For sharpness testing, plain printer paper was used. Mondi Rotatrim 160C1E ENVIROWHITE 80 g/m^2 A4 paper (Mondi Limited, Melrose Arch, South Africa) was guillotined into quarters (equivalent to an A6 page size), and each quarter folded in half. The experimental sheet is shown in Figure 4. Seventeen of these experimental sheets were used for unsonicated incisions and seventeen for sonicated incisions. Incisions were made manually by the researcher using a forward motion along the length of the blade through the fold at two positions.

The incisions were optically evaluated using a CKX31 inverted microscope (Olympus Corporation, Shinjuku, Tokyo, Japan) with a C-Plan 10× objective lens (Olympus) that has a numerical aperture of 0.25 and a working distance of 10.6 mm. Each experimental sheet was observed at eight positions on the industrially cut edge (E1-E8 in Figure 4) and at eight positions on the incisions made (F1-F8 in Figure 4).

3. RESULTS AND DISCUSSION

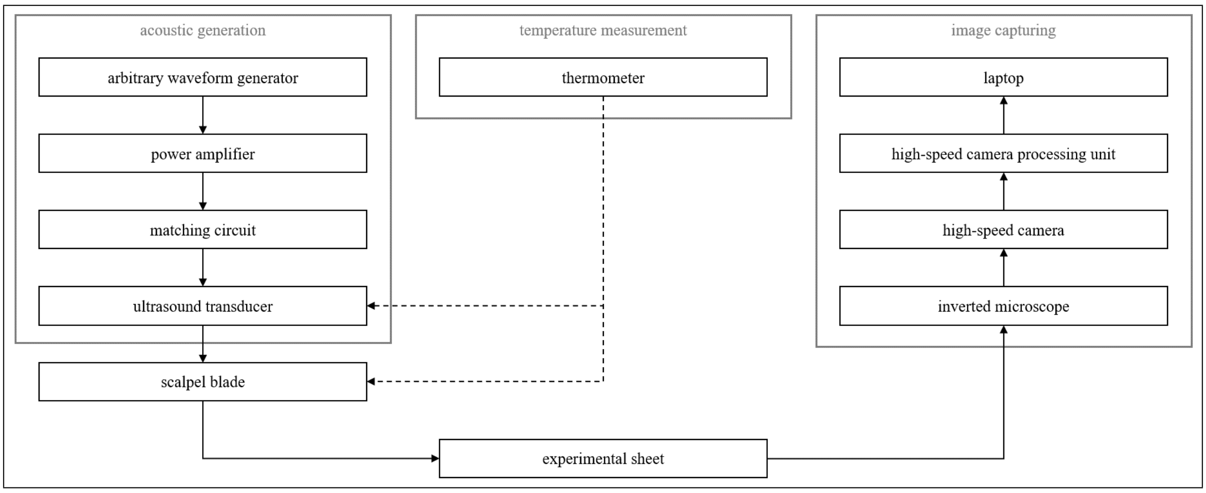
The maximum temperature measured during the 15 minute measurement period was 36.7 °C and 21.4 °C over the ultrasound transducer and at the blade respectively, at an ambient temperature of 21.0 °C. The maximum temperature occurred at 3 minutes. Thereafter the system stabilised where the generation of heat matched the dissipation to the surrounding environment. As seen in Figure 5, under sonication the temperature over the ultrasound transducer increased by an average of 14.7 °C (median of 15.5 °C, maximum of 17.0 °C). In comparison, the temperature at the blade increased by an average of 0.4 °C (median of 0.4 °C, maximum of 0.6 °C).

Each experimental sheet was optically evaluated along the incisions resulting in a total sample size of 136 for both the control and the experiment, with an average length of 14 mm and a standard deviation of 1 mm. Incisions outside of this range were excluded from the experiment. Thus analysis was considered for 116 unsonicated samples, and 124 sonicated samples.

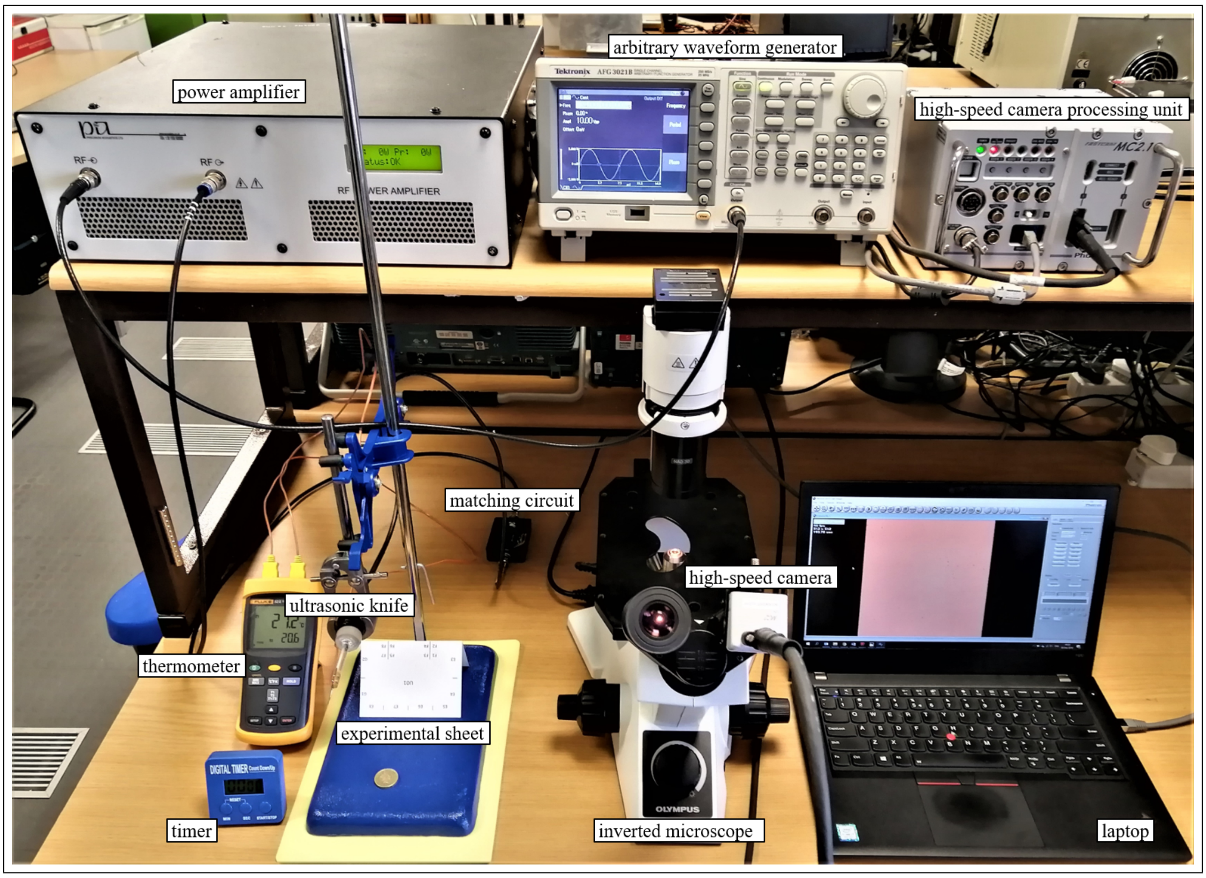
Figure 6 shows a sample of images of the edge of an industrially-cut sheet of paper as well as demonstration of the incision made by a blunt blade with and without sonication. When cutting with the blade without sonication, the edge of the incision is tortuous with multiple paper fibres visible. In contrast, the incision of the blade with sonication has limited visible paper fibres and a well-defined, non-tortuous edge. The edge of an industrially cut sheet of paper has distinct paper fibres in various planes of focus. Comparing the incision produced by the blade without sonication to the incision produced by the blade with sonication, it is clear that sonication significantly improves the sharpness of the cut. The incision made by the blade with sonication appears to be as sharp as the edge of the industrially cut paper. This indicates that sonication has a sharpening effect on blunt blades. This finding may have implications for multiple fields reliant on sharp, precision cutting.

4. CONCLUSIONS

Blades lose their sharpness over time with every cut made. This paper presented a set-up of an ultrasonic knife with an interchangeable blade which showed an average temperature increase of 0.4 °C at the blade whilst improving the cutting ability. Using a continuous 134-kHz 10-V peak-to-peak input signal the ultrasonic knife was confirmed to have fewer visible paper fibres on the edge of the cut when compared to without



(a)



(b)

Figure 1: A schematic (a) and photograph (b) of the experimental set-up.

sonication. Further to this, the sonicated cut appears to be as clean as the industrially cut paper edges. The potential impacts of this technology are in industrial cutting, clean shaving, and precision surgery.

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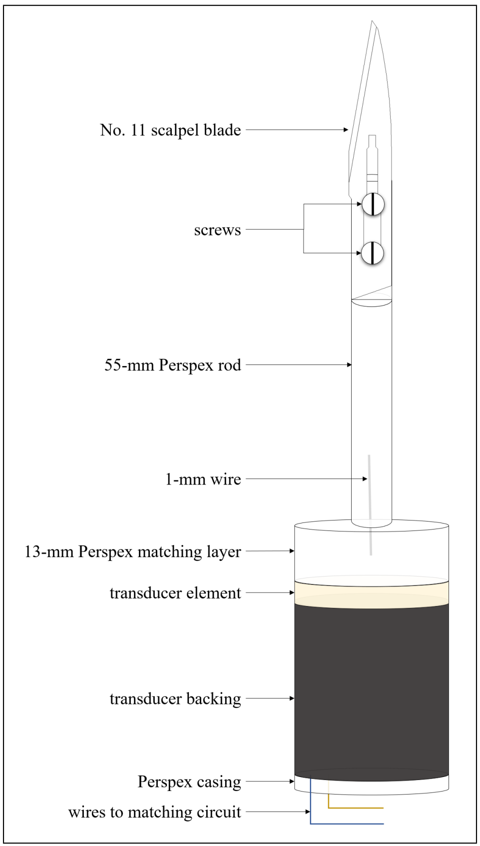

Figure 2: Ultrasonic cutting device with a single element ultrasound transducer and a scalpel blade attached with screws to a 55-mm Perspex rod.

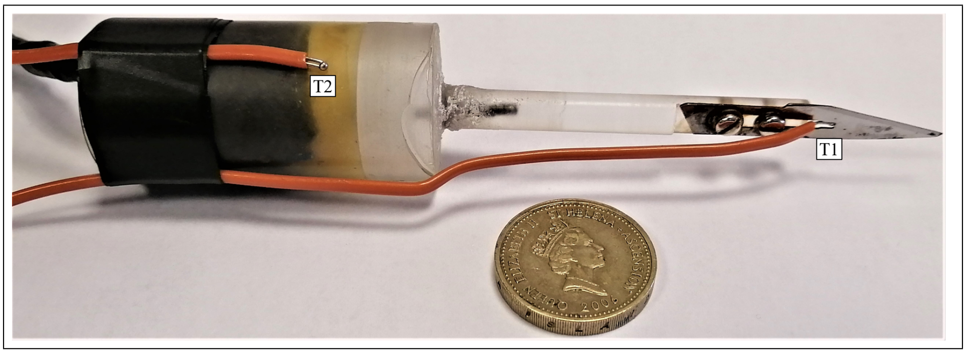

Figure 3: Position of the temperature probes on the ultrasonic knife on the blade (T1) and over the ultrasound transducer (T2).

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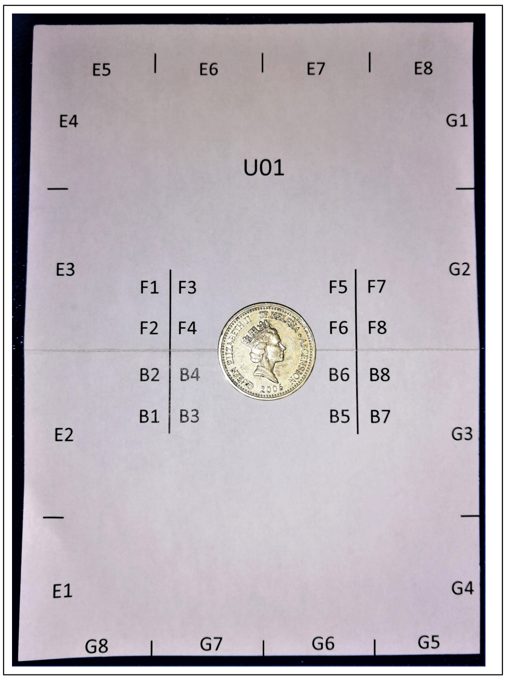

Figure 4: A6-sized experimental sheet with marks indicating the industrially cut edge (E1-E8) and along the incisions (F1-F8).

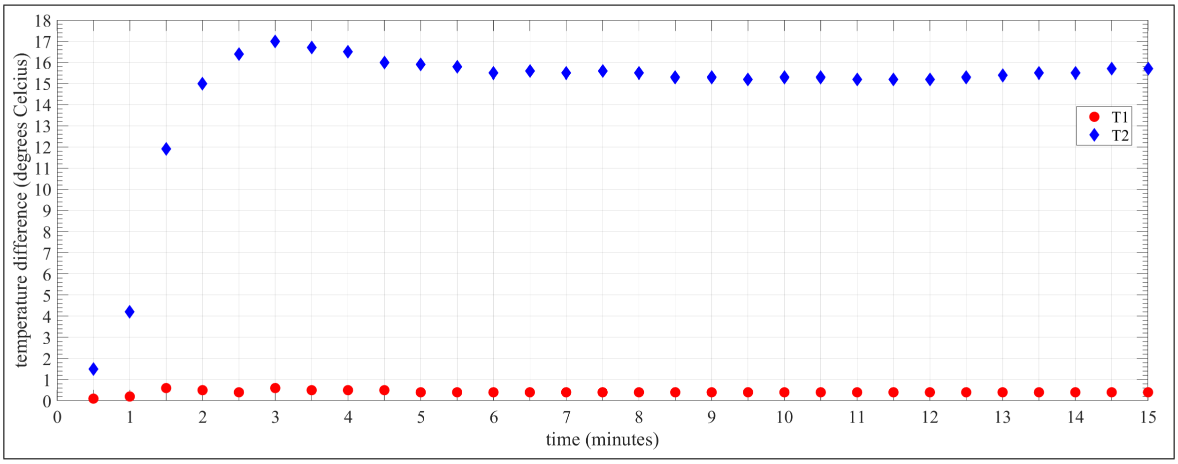

Figure 5: Temperature difference over a 15 minute period with the ultrasonic knife under sonication. The red dots indicate the temperature difference at the blade (T1) and blue diamonds indicate the temperature difference over the ultrasound transducer (T2).

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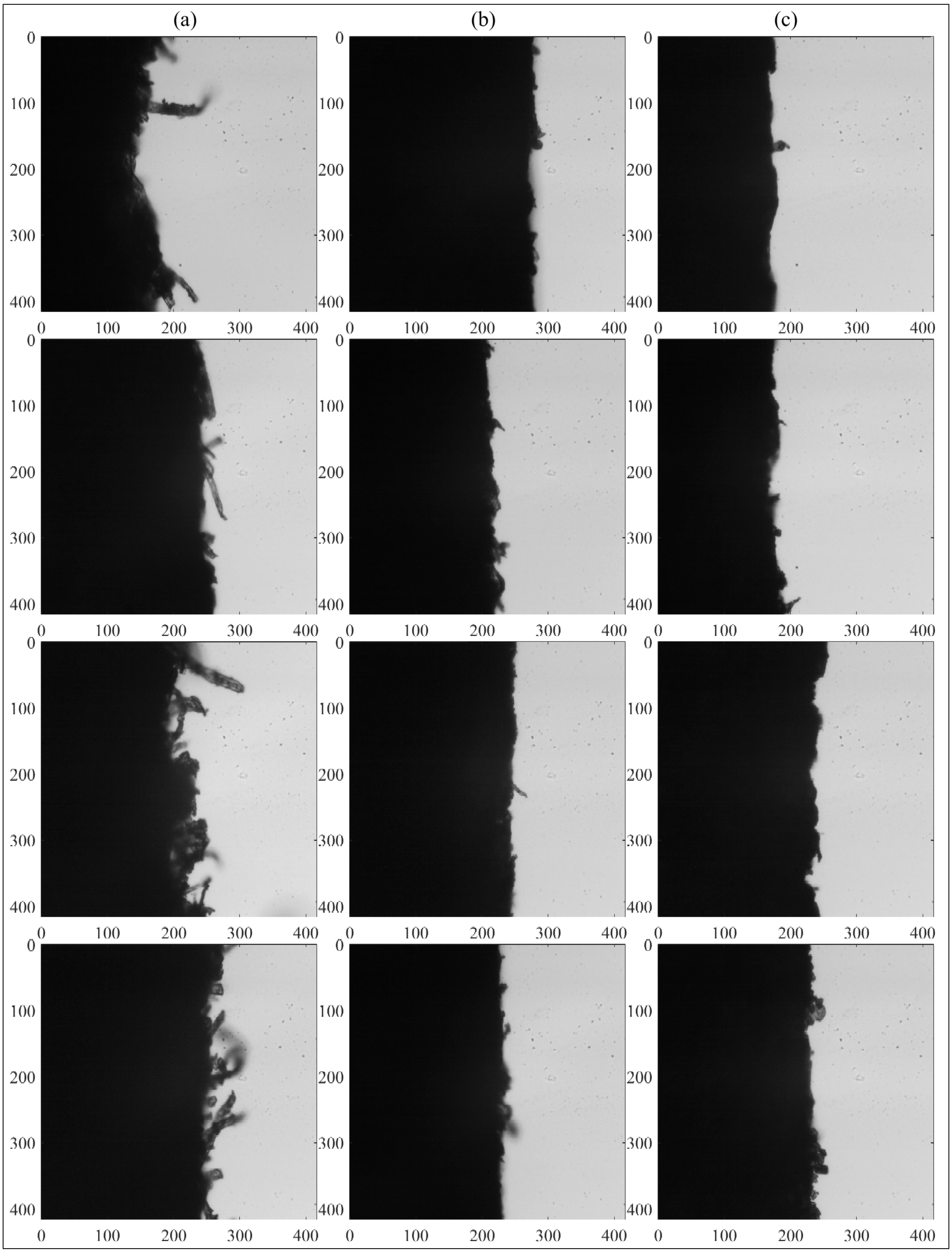

Figure 6: Back-lit bright-field 10× microscopy images of incisions in paper from an unsonicated blunt blade (a) and a sonicated blunt blade (b), compared to the paper edge from sharp industrial cutting (c). The darks areas represent the paper. Each frame corresponds to a 416 × 416 (μm^2) area.