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Fabrication of High-temperature Flexible Ultrasonic Transducer by Printing Method
印刷法を用いた高温フレキシブル超音波トランスデューサーの作製

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1. Introduction

Ultrasonic non-destructive testing (NDT) is used in various industries for cost effectiveness and sub-surface defect/flaw detection capability. Ultrasonic transducers made by sol-gel composite could be good candidates for industrial applications because of high temperature durability, high-signal-to-noise ratio (SNR), and physical flexibility when sol-gel composite films are fabricated onto flexible substrate, such as metal foil. Since industrial structures have many curved surfaces and the surface temperature could be high during operation so flexible high temperature ultrasonic transducers have been desired.

Fabrication cost of stencil printing method could be lower than spray method due to short fabrication time. However, fabrication of flexible ultrasonic transducer made by stencil printing method is difficult and low film adhesion strength was an issue. In this study, PZT/PZT films were fabricated by stencil printing method on metal foil substrates. In order to improve adhesion strength, films were coated with silicone.

2. Fabrication process

Plastic stencil masks were used for patterning facility, curved surface suitability and low cost. Mask pattern was ~10mm diameter circle. Mask pattern was made by laser cutting. Films were fabricated on stainless steel substrates with dimensions of 30μm thickness, ~20mm length, and ~20mm width. Stainless steel substrates were chosen because of high temperature durability.

After stencil masks and substrates were prepared, the stencil mask was placed on a substrate and covered with paint material, i.e. mixture of PZT powder and PZT sol-gel solution, by a squeegee. The similar materials with spray method could be used for stencil printing method, though it made slight modification because suitable viscosity for stencil printing method was higher than that spray method. In this time, stencil printing methods with non-fixing and fixing conditions were compared. The substrate fixing condition was accomplished by rotary pump. After stencil printing process, similar thermal treatments with traditional spray method, such as drying process at 150 °C by a hot plate, annealing process at 650 °C by a furnace, were carried out. Room temperature poling was operated by corona discharge. Since film which was fabricated by stencil printing is fragile, film was covered by silicone by painting. The cross section image of film structure was shown in **Fig. 1**.

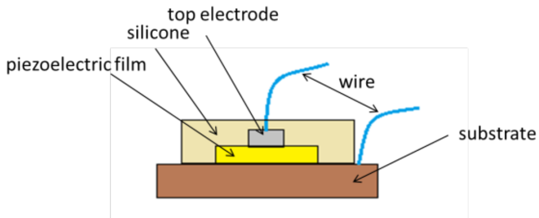
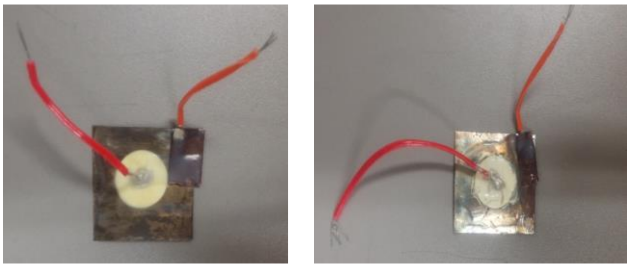


Fig.1 PZT/PZT flexible ultrasonic transducer.

3. Experimental results

The optical images of two samples were shown in **Fig. 2**. Film thickness of each sample without fixing and with fixing was ~35μm and ~110μm, respectively. Piezoelectric constant d_{33} of each sample without fixing and with fixing was 21.2 pC/N and 34.7 pC/N, respectively. Ultrasonic measurements from 4mm thick aluminum plate were attempted and clear reflected echoes were observed as shown in **Figs. 3-4** by both ultrasonic transducers and signal strength was comparable with traditional spray coating method. FFT results of Figs. 3-4 are shown in **Figs. 5-6** and center frequency of without and with fixing stencil printing samples was ~8.14MHz and ~13.05MHz, respectively. By non-fixing stencil printing, lower center frequency was achieved even though the film thickness was lower. Suspected reason was higher porosity. However, yield ratio by non-fixing stencil printing was much lower. Since lower frequency is generally preferable for NDT applications so material preparation optimization should be investigated for fixing stencil printing process in order to increase porosity.



(a) (b)

Fig.2 PZT/PZT ultrasonic transducer optical images made by (a) non-fixing and (b) fixing stencil printing.

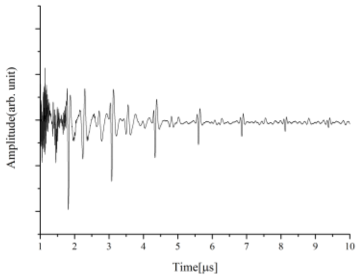


Fig.3 Ultrasonic measurement result from 4mm thick aluminum plate by Fig.2 (a).

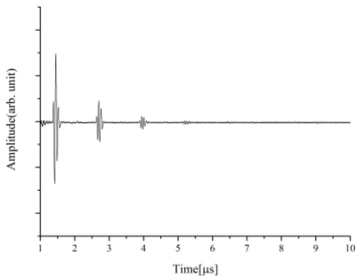


Fig.4 Ultrasonic measurement result from 4mm thick aluminum plate by Fig.2 (b).

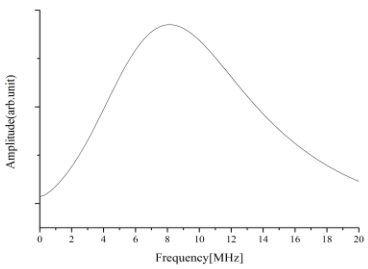


Fig.5 FFT result of Fig. 3.

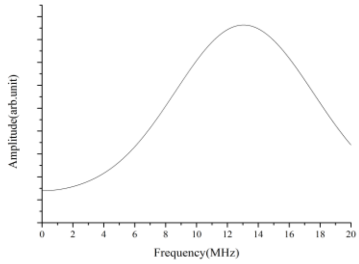


Fig.6 FFT result of Fig. 4.

In order to demonstrate flexibility, the steel pipe with ~4mm thick and ~40mm outer diameter was measured by the ultrasonic transducer shown in Fig. 2(b) and measurement result was shown in **Fig. 7**. It should be noticed that almost same signal strength was achieved with that from flat surface measurement shown in Fig. 4.

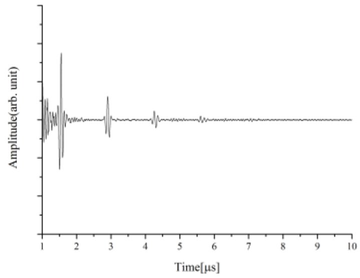


Fig.7 Ultrasonic measurement result from steel pipe with 4mm thick and ~40mm outer diameter.

4. Conclusions

PZT/PZT flexible ultrasonic transducers were manufactured by stencil printing process. PZT/PZT films by stencil printing obtained high bending durability by silicone overlapping. Signal strength was comparable with traditional spray coating process. A steel pipe with 4mm thick and ~40mm outer diameter was successfully monitored by a PZT/PZT flexible ultrasonic transducer by stencil printing.

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