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Standalone High Temperature Broadband Ultrasonic Transducers for Non-Destructive Testing

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1. Introduction

In the energy sector, particularly in the power industry, it is highly costly to impede the operation of any plant. However, many installations such as nuclear power plants have either reached their original designed life span or passed it. Thus it is vital to evaluate the health condition of the plant without taking it off-line and in the meantime to maintain its efficient operation to reduce costs and ensure public safety. Since many of the equipments involved in the power industry operate at high temperatures (HT), HT ultrasonic non-destructive testing (NDT) or structural health monitoring (SHM) using ultrasonic transducers (UTs) [1-3] and techniques is of considerable interest. Broad frequency bandwidth UTs are also desired to achieve high spatial resolution such as for pipe thickness measurements or defect size inspections.

In general HT broadband frequency bandwidth UT may be achieved by using a backing, which serves as an ultrasonic energy damper [2,3] or bonding the UT onto a delay line [1]. However, both approaches tend to make the UT bulky and non-flexible. It is also difficult to fabricate the backing for appropriate HT measurements. In this study an alternative way to fabricate standalone HT broad bandwidth UTs will be presented.

2. Fabrication of Piezoelectric HT UTs

Firstly, piezoelectric thick lead zirconate titanate composite (PZT-c) films are fabricated by the sol-gel spray technology [4, 5]. Using a shadow mask with 10 mm diameter openings PZT-c composite films with this diameter are made onto 75 µm thick titanium (Ti) foils and fabricated into flexible ultrasonic transducer (FUT) [5]. Each individual 10 mm diameter PZT-c film with an 8 mm diameter painted top silver paste electrode are cut into separate FUT elements as shown in **Fig. 1**. The thickness of the PZT-c film are determined and fabricated according to the desired center operation frequency of the HTUT. This FUT is then glued onto a HTUT holder made of aluminum (Al) consisting of a HT connector, a circular tube holder with a diameter of 15 mm and 1 mm Al tube wall thickness. Here glue that functions at up to 150°C is used. A thin electrical wire is connected between the top silver paste electrode and the center line of the connector with a HT conducting paste. The electrical ground line of the connector is connected with the Al tube holder and the Ti foil. Two stand alone HTUTs are shown in **Fig. 2** and they can function at up to 150°C.

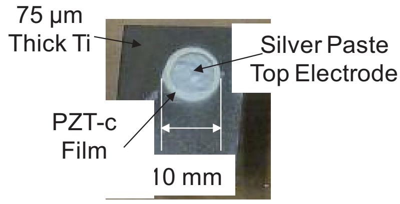

Fig.1 One FUT on a 75 µm thick Ti foil.

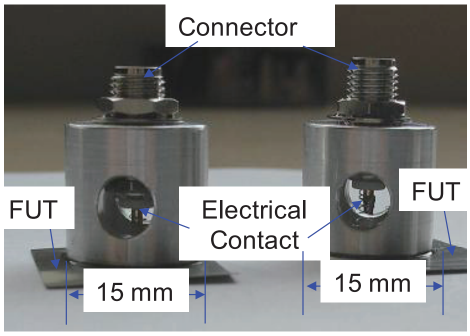

Fig.2 Two standalone HTUTs employing FUT.

3. Experimental Results

Fig. 3 shows an experimental setup for the ultrasonic measurements performed at 150°C using a handheld EPOCH model 1000 ultrasonic pulser-receiver. As a standalone HTUT, a commercially available gel is used between the probing surface of the HTUT and the object to be measured or tested. **Fig. 4a** and **Fig. 4b** show the pulse-echo measurement on a 12.5 mm thick steel plate as shown in Fig. 3 at room temperature and at 150°C, respectively, where L_n is the n^{th} trip echo through the steel plate thickness. The experimental settings are the same for both Fig. 4a and Fig. 4b. The center frequencies and 6 dB bandwidth for the L_2 echoes reflected from the bottom surface of this steel plate at room temperature and 150°C are 8.5 and 7.5 MHz, and 3.0 and 1.5 MHz, respectively. The signal strength at 150°C is about 7 dB weaker than that at room temperature. The main

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contribution to both the reduction in signal strength and in the 6 dB bandwidth may be due to the decreased piezoelectricity and the HT couplant effect at 150°C.

In the investigation, three different PZT-c film thicknesses for the FUT of the standalone HTUT have been made. They resulted from 10, 20 and 26 layers of sol-gel sprayed coating. At room temperature, the center frequencies of the L_2 echo reflected from the bottom surface of the Al plate for these three different thicknesses are 10.8 MHz, 9.6 MHz and 8.3 MHz. As expected, the higher number of coating leads to thicker PZT-c films, producing lower center frequencies.

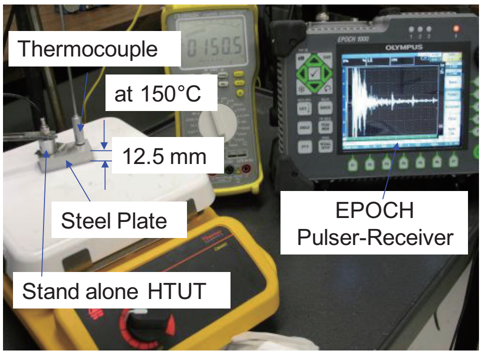
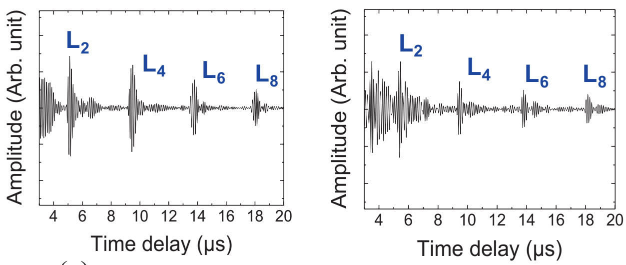


Fig.3 Setup for measurement of a plate at 150°C.



(a) Room temperature (b) 150°C
Fig.4 Pulse-echo measurements on a steel plate.

Since the probing side of the standalone HTUT is made of FUT, it has a certain amount of flexibility and it was therefore attached to a steel pipe with an outer diameter (OD) of 89 mm and a wall thickness of 6.5 mm. The ultrasonic measurement setup at 150°C is shown in **Fig. 5**. **Fig. 6a** and **Fig. 6b** present the signals obtained during pulse-echo measurements at room temperature and at 150°C, respectively, where L_n is the n^{th} trip echo through the pipe wall thickness. Since the probing surface of the current holder design is a circle, it will be modified to be a rectangular so that the long axis of the FUT of the HTUT may be aligned with the axis of the pipe to be tested and fully conformed to the curvature of the pipe. The top electrode can be rectangular and the long axis can be made parallel to the pipe axis as well.

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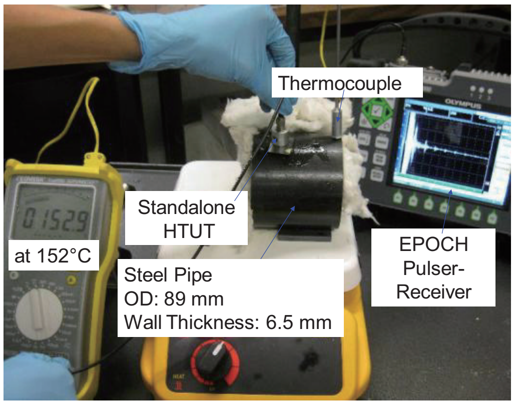
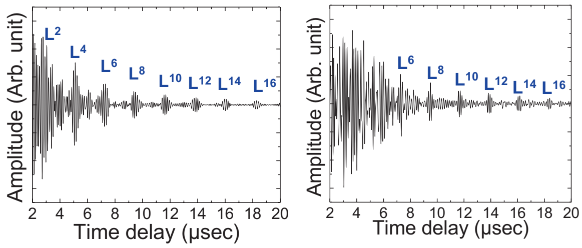


Fig.5 Setup for measurement of a pipe at 150°C.



(a) Room temperature (b) 150°C
Fig.6 Pulse-echo measurements on a steel pipe.

4. Conclusions

The fabrication of standalone 150°C piezoelectric UT was presented. It consists of a PZT-c film based FUT bonded onto an Al holder with connectors and proper electrical connection. It has been used to measure a flat steel plate and a steel pipe at temperatures of up to 150°C. A commercially available gel was used between the probing surface of the HT UT and the sample to be measured. At 150°C, the signal is about 7 dB weaker than that obtained at room temperature.

Acknowledgment

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