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High Temperature Broadband Ultrasonic Transducers for Structural Health Monitoring and Non-Destructive Testing
構造健全診断及び非破壊検査を目的とした広帯域高温超音波トランスデューサの開発

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1. Introduction

Structural health monitoring (SHM) and non-destructive testing (NDT) have been desired in nuclear and petroleum plants and manufacturing facilities operating at high temperature (HT) in order to improve the safety and to extend their life span. Ultrasonic transducers (UTs) are often used in SHM and NDT due to the non-destructive and non-intrusive testing ability and relatively low cost [1, 2]. Broadband frequency characteristic is also important because high spatial resolution can be obtained from short ultrasonic pulse width.

However, it is difficult to find commercial available broadband UTs which can operate at HT and curved surfaces. Tungsten/epoxy composite is commonly glued to piezoelectric crystals as backing material to realise the broad frequency bandwidth. Often epoxy starts to change their charactersitics above the glass transition temperature between 100 and 200°C. Also epoxy is often diassembled at HT because its thermal expansion coefficient is quite different from that of metallic electrodes or piezoelectric crystals. As a result, NDT by UTs is normally operated at room temperature during shutdown. Such shutdown causes significant economical loss and inconvenience.

There were reports of the development of HT broadband integrated UTs (IUTs) by a sol-gel spray technique [3,4]. Thick piezoelectric films were directly fabricted onto the monitored structures. Also piezoelectric films were fabricated onto metallic or polymer membranes and such flexible UTs (FUTs) could be permanently bonded onto the target structures to realize IUTs for SHM purposes. But in certain applications, ultrasonic NDT at HT for many different locations are desired. In this case, HT ultrasonic couplant is required but it makes the inspection challenging. At HT, liquid or paste type couplants dry relatively quickly within seconds or tens of seconds depending on the temperature so that the inspection time is limited. Soft metal foil could be useful as HT couplant. However, it requires relatively high pressure.

In this paper, two kinds of HT measurement methods, FUT and IUT integrated onto a magnetic buffer rod were investigated with object temperature up to 300°C.

2. Bismuth titanate composite (BIT-c) FUT

FUTs consisting of 30mm×40mm×75µm titanium (Ti) foil, 15mm×20mm BIT-c film, and a silver top electrode with 8mm diameter were prepared for this experiment. BIT-c films were made by BIT powders together with lead zirconate titanate (PZT) sol-gel solution using a sol-gel spray technique. BIT-c films were chosen as piezoelectric materials because such they showed stable operations up to at least 450°C [3, 4]. A FUT connected with a Teflon cable, a connector and polyimide protection tape which can work up to 300°C is shown in **Fig. 1(a)**. The center frequency and 6dB bandwidth of this FUT were around 10.7MHz and 6.5MHz, respectively.

In order to demonstrate NDT capability at HT for curved surfaces such as pipes, HT thickness measurement of a steel pipe in pulse-echo mode was attempted at 300°C by the FUT as shown in Fig.1 (a). The steel pipe was heated and the surface temperature was monitored with a thermocouple. The connector was connected to a pulser/receiver. A HT couplant was placed between the FUT and the pipe which has a outer diameter (OD) of 76 mm and a wall thickness of 6mm and a good contact was achieved by using hands with HT gloves. The ultrasonic pulse/echo performance in the time domain at 300°C is shown in **Fig. 1(b)**. L_2, L_4, L_6 and L_8 are the 2nd, 4th, 6th and 8th reflected echoes, respectively, through thin Ti foil, couplant, and the wall thickness of the steel pipe. At 300°C, L_2 was observed partially because of the too long recovery time of the receiver amplifier used. L_4, L_6 and L_8 have excellent signal-to-noise ratio (SNR). It can be seen that such FUT together with HT couplant can be used for HT NDT of pipes. Such FUT is sufficient flexible to inspect pipes of OD more than 15 mm.

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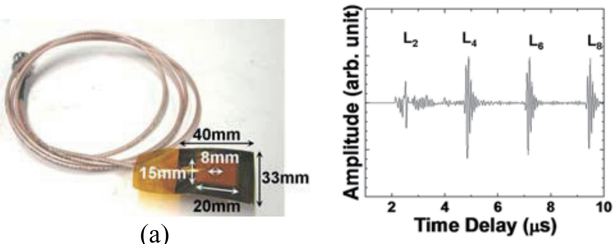
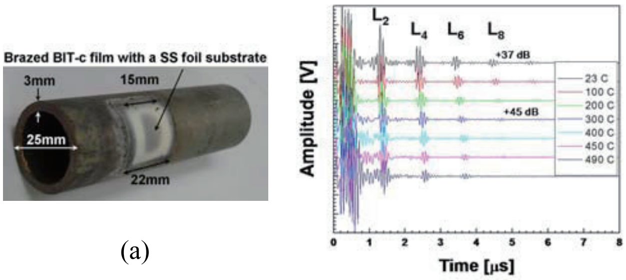


(a)

(b)

Fig. 1 (a) A BIT-c FUT on a Ti membrane and (b) its performance on a pipe at 300°C

For SHM UTs are required to be integrated with structures. It is always considered a challenge task to bond the UTs onto structures for HT measurements without the concern of thermal cycling. In this study a novel approach using brazing technique is investigated. In order to braze FUTs onto steel pipes FUTs using 75µm thick stainless steel (SS) membranes are chosen. The brazing material between the SS membrane and steel pipe serves both as the bonding material and ultrasonic couplant. Therefore a FUT consisting of 20mm×20mm×75µm SS membrane, 15mm×15mm BIT-c film with 10MHz center frequency was fabricated. A special brazing material was placed between this FUT and a steel pipe with 3mm wall thickness and 25mm OD. The brazing using an induction heating facility equipped with temperature and time control was operated around 800°C together with adding the positive pressure between FUT and the steel pipe. The sample after brazing shown in **Fig. 2(a)** was heated in a furnace and **Fig. 2(b)** shows the ultrasonic pulse/echo performance in the time domain at various temperatures. L_2, L_4, and L_6 are the 2nd, 4th and 6th reflected echoes, respectively, through the pipe wall thickness. Even at 490°C, multiple echoes with good SNR were clearly observed. It indicates that FUTs with such brazing technique can be useful for HT SHM applications up to at least 490°C.



(a)

(b)

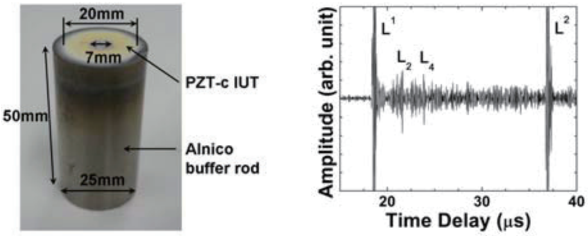
Fig. 2 Brazed BIT-c film onto a steel pipe and (b) its ultrasonic performance at various temperatures

3. IUT onto a magnetic buffer rod

Buffer rod delay line method is often used for HT NDT because the temperature at the UT end can be much lower than the probing end. There may be no blind zone if the length of a buffer rod is properly chosen. [4]. IUT with a buffer rod is good combination because there is no cooling system nor ultrasonic couplant between IUT and rod required. In this study, a buffer rod is made of HT magnetic material is studied, because it may be easily installed onto steel structures for HT NDT.

A HT probe consisting of 25mm diameter, 50mm length alnico magnetic rod, a 20mm diameter PZT composite (PZT-c) film, and a 7mm diameter silver top electrode was prepared for this experiment as shown in **Fig. 3(a)**. As magnetic material, alnico was chosen because of its high Curie temperature. PZT-c films, made by PZT powders together with PZT sol-gel solution using a sol-gel spray technique, were chosen as piezoelectric materials due to the high signal strength. The center frequency of the 1st reflected echo from the end of the rod was around 16MHz.

The ultrasonic pulse/echo performance in the time domain at 300°C is shown in **Fig. 3(b)**. L_2, L_4, and L_6 are the 2nd, 4th, 6th reflected echoes, respectively through the HT ultrasonic couplant, and a 7mm thick steel plate after L^1 and L^n is the nth round trip echo through the alnico rod. The signal strength and SNR became significantly lower at 300°C and reasons were higher attenuation of alnico at 16MHz and ineffectiveness of the couplant at 300°C.



(a)

(b)

Fig. 3 PZT-c IUT onto a magnetic buffer rod and (b) its ultrasonic performance at 300°C

4. Conclusions

Two kinds of HT broadband UTs, BIT-c FUT and PZT-c IUT with a magnetic buffer rod were demonstrated and promising results for SHM and NDT applications were obtained, respectively. When the monitored steel substrate temperatures were at 300°C, multiple reflected echoes were clearly observed during NDT and SHM.

References

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