High temperature ultrasonic probes and their potential applications

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High Temperature Ultrasonic Probes and Their Potential Applications
高温超音波プローブ及びその応用可能性

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1. Introduction

Ultrasonic nondestructive evaluation (NDE) of materials, parts and structures [1-4] has played a vital role in many industries involving improvement of reliablity, safety, service life extension, maintenance cost reduction, etc. Increasingly ultrasound is used for structural health monitoring (SHM) [3,5,6] for aerospace components, nuclear and electrical power plants, petroleum plants, engines, etc. For aerospace sector SHM facilitates condition based maintenance to estimate the remaining useful life on a continuous basis and also enable modern light-weight aircraft designs with increased safety and cost reductions. Also due to the high demand on non-stop supplying of energy, SHM and NDE are crucial to extend the life span of every nuclear power, electric power and petroleum plant, and land based engines, the time span between two adjacent showdowns for plant and engine inspections and also each shutdown time. Furthermore, globle market demands high quality products manufactured by cost-effective technologies and technical specifications are increasingly advanced and precise. The required quality control for these manufacturing technologies desires on-line process diagnostics (OPD) [4,7]. Ultrasound is one attractive OPD approach. This study involves NDE, SHM and OPD using ultrasound at high temperatures (HT) [1-7].

2. HT transducers and buffer rods approaches

Two approaches to achieve HT ultrasonic measurements are used. One is to use HT thick (>30μm) film ultrasonic transducers (UTs) made by a sol-gel spray fabrication process [3,5,6,8]. It consists of six main steps: (1) preparing high dielectric constant solution, (2) ball milling of piezoelectric ceramic powders to submicron size, (3) film spraying using slurries from steps (1) and (2) to produce a layer of piezoelectric composite ceramic film, (4) heat treatment to produce a solid film, (5) corona poling to obtain piezoelectricity, and (6) top electrode fabrication. Steps (3) and (4) are used multiple times to produce proper piezoelectric film thickness for optimal ultrasonic operating frequencies. In this operating frequencies. investigation lead-zirconate-titanate (PZT) solution is used for step (1). Piezoelectric PZT, bismuth titanate (BIT) and lithium niobate (LN) powders are used for the fabrication of HT piezoelectric composite film PZT/PZT, BIT/PZT and LN/PZT ultrasonic transducers (UTs) to operate reliably up to 150°C, 450°C, 750°C, respectively. They can be directly coated and used as integrated UTs (IUTs). If the substrate is thin, then such HT UTs can be made as flexible UTs (FUTs) [8]. All HT IUTs and FUTs can be used for SHM and NDE of objects with curved surfaces [3,5,6,8].

Another approach involves the use of HT delay line buffer rods. In this investigation clad buffer rods consisting of core and cladding [2,7] and non-clad buffer rods [1,3,9] are used. The advantages using buffer rods is that the temperature of the probing end can be much higher than the UT end. The well known issues to use the long delay line buffer rods are the presence of spurious echoes due to one or more of: mode conversion, wave reverberation and diffraction within the rod of finite diameter. These echoes are unwanted because of their possible interference with the desired signals from the measured sample. These noises can be reduced significantly using clad geometry [2,7] and tapered and/or thread shapes [9], thus signals with high signal-to noise ratio (SNR) can be obtained. In this study only longitudinal (L) waves are used.

3. Different HT UTs and ultrasonic probes

The evaluation of the ultrasonic strength of all HTUTs and probes will be based on a commercially available EPOCH (model LT) pulser-receiver device which has receiver gain up to 100dB. This handheld device is commonly used in the NDT industry. The electrical contacts during all measurements were carried out using a spring-loaded two- pin probe. **Fig.1** shows a 79μm thick BIT/PZT film IUT deposited onto a steel substrate of 12.7 mm thick and measured by the EPOCH device at 400°C. At 400°C 47.4dB gain, out of the available 100 dB receiver gain was used to produce the 1st echo reflected from the end of

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the plate. The centre frequency and the 6dB bandwidth are 5.5MHz and 4.6MHz respectively. **Fig.2** shows that the HT IUTs shown in **Fig.1** are used as sensors incorporated into mold (or die) inserts for OPD of polymer injection molding (IM) [7] and light-weight metal IM or die casting.

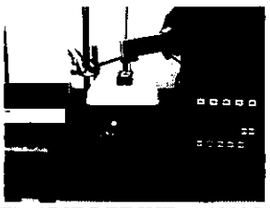

Fig.1BIT/PZT IUT at 400°C.

Fig.2 Four HT IUTs

Fig.3 shows the HT measurement setup of a FUT having a ~70μm thick BIT/PZT film deposited onto a 38μm thick stainless steel which is bonded onto a 12.7mm thick steel substrate using a metallic adhesive at 303°C. The measured ultrasonic data gone through a high pass filter is presented in **Fig.4**. L^n is the nth round trip L echo through the plate thickness The centre frequency and the 6dB bandwidth of the L^1 echo at 300°C were 10.7MHz and 8.2MHz, respectively. Using EPOCH 69dB out of the available 100dB receiver gain was used.

Fig.1BIT/PZT FUT at 303°C.

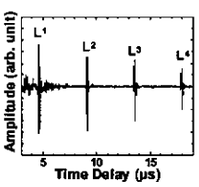

Fig.4 Signals at 300°C.

When a clad buffer rod consists of a 12.7mm steel core and 1mm thick stainless steel cladding as shown in **Fig.5** is used together with a 106μm thick 150°C PZT/PZT IUT deposited onto its one end, the measurement setup shown in Fig.6 demonstrates that the probing end of the clad rod can operate at a higher temperature (182°C). If the length is longer, the probing temperature can be higher. In **Fig.6** at 151°C only 10dB out of the available 100dB receiver gain of EPOCH was used. At 150°C the centre frequency and the 6dB bandwidth of the L^1 echo were 7.0MHz and 5.9MHz, respectively.

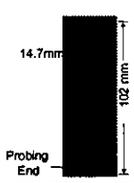

Fig.5 PZT/PZT IUT on a clad rod.

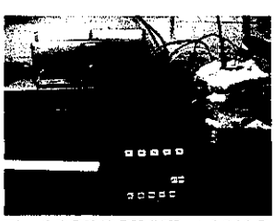

Fig.6 PZT/PZT UT at 151°C.

Fig.7 and **Fig.8** show thick PZT/PZT and BIT/PZT film IUT onto two non-clad tapered rods and a clad steel buffer rod, respectively. Their center frequencies are near 5MHz. The former two are used for OPD of polymer extrusion [7] without the need of any cooling. It may be used from the feed hopper down to the extruder die. The latter is used as the immersion HT UT for the remaining wall thickness profile measurement of the container inside the 450°C molten zinc. The steel wall thickness is normally 60mm. Thickness reduction is caused by the corrosion which may be unpredictable due to uneven heating profile. Such thickness measurement is one of the most important NDE for hot-dip galvanization industry.

Fig.7 PZT/PZT IUT with non-clad rod.

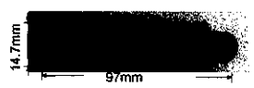

Fig.8 BIT/PZT IUT with clad rod

4. Conclusions

HTUTs including BIT/PZT and PZT/PZT IUTs or FUTs made by sol-gel sprayed techniques can be used for SHM and NDE purposes. Together with metal plate, clad and non-clad buffer rod delay lines they can be used as mold (or die) insert sensors for OPD of polymer or metal IM and polymer extrusion, and container wall thickness profile measurement in molten zinc.

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