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High Temperature Integrated Ultrasonic Transducers for Light-Weight Metal Process Monitoring

高温一体型超音波トランスジューサによる
 軽金属成形モニタリングの検討

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1. Introduction

Light weight and high mechanical strength metals such as magnesium (Mg) and aluminum (Al) alloys have become increasingly used for manufacturers in automobile industry in order to enhance fuel-efficiency for ecology purpose. Liquid and semi-solid diecasting and thixomolding (injection molding of Mg alloys) are commonly used production technologies for such materials. High production rate and yield, and quality assurance are crucial factors to ensure the success of these technologies and the increase of the use of these materials.

Due to high pressure and high temperature (HT) and corrosive natures of Mg and Al in the molten state during the above mentioned production processes, it is not simple to perform on-line monitoring of temperature, pressure, microstructure, filling conditions and solidification of the melt. In the past delay line ultrasonic probes [1] have been utilized to perform real-time monitoring of Al and Mg alloy diecasting processes, however, these probes needed cooling and were bulky. Holes were required to be made in the die so that these probes can be accommodated. It means that they are invasive sensors. Furthermore, due to the HT and high pressure of the diecasting and thixomolding processes the safety requirements prohibit the use of the above mentioned invasive delay line ultrasonic probes at the nozzle. Any leak of molten metals at any hole which accommodates the invasive probe may lead to serious hazards to human lives. However, current commercially available broadband ultrasonic transducers (UTs) have limitations for HT operations due to the lack of appropriate HT couplant and backing material. They are also not convenient for use at curved surfaces and not reliable under thermal shock or vibration conditions. Therefore HT non-invasive UTs are desired for above mentioned real-time process monitoring applications.

HT integrated UT (IUT) using piezoelectric composite ceramic films made by sol-gel spray

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technique were reported [2,3]. These IUTs can be directly fabricated onto curved surfaces such as nozzles and die or mold inserts, do not need ultrasonic couplant and have high signal strength and broad bandwidth. They seem suitable for real-time non-invasive monitoring of diecasting and thixomolding processes.

Toward the demonstration of IUTs' suitability for the above mentioned application directions, in this study, two kinds of IUTs were fabricated onto different substrates. Lithium niobate (LN)/ lead-zirconate-titanate (PZT) IUTs [3] were fabricated onto a titanium rod and a steel pipe, and bismuth titanate (BIT)/PZT IUTs were fabricated onto a real thixomolding mold insert in order to investigate their HT ultrasonic performance, thermal shock and cycling resistance.

2. LN/PZT IUT onto a titanium substrate

A LN/PZT IUT was fabricated onto a 25.4mm diameter and 26.3mm height titanium rod with around 10mm square platinum top electrode as shown in Fig.1. The detailed description of fabrication procedure for sol-gel spray technique can be found elsewhere [2, 3]. Titanium rod and platinum paste top electrode were selected because of their high temperature durability.

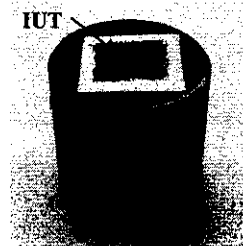


Fig.1 LN/PZT IUT onto a titanium rod.

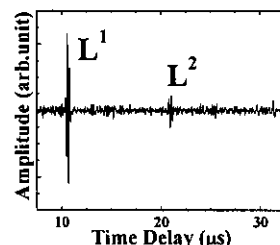


Fig.2 Ultrasonic performance of IUT in Fig.1 at 800°C

To examine the thermal shock resistance and HT operation capability, a propane gas torch was used to heat the LN/PZT IUT shown in Fig. 1. Fig.2 shows the 1st, L¹, and 2nd round-trip, L², reflected echoes from the bottom of substrate through the thickness of the rod. The center frequency, 6dB bandwidth and signal to noise ratio (SNR) of the L¹

echo are 4.5MHz, 3.1MHz and 21dB, respectively. It is noted that thermal cycling using the propane gas torch as the heating source was executed 5 times between room temperature and 800°C and no signal deterioration was observed. Since the temperature at the nozzle of the thixomolding or of a diecasting machine is up to a maximum of about 620°C, it is expected that LN/PZT IUTs are attractive and practical non-invasive ultrasonic sensors for process monitoring at those locations.

3. LN/PZT IUTs onto a steel pipe

In order to simulate the nozzle, a steel pipe with an inner diameter of 14.3mm, outer diameter of 38.2mm, and length of 43.5mm was chosen as a substrate. It is noted that normally the nozzle of the thixomolding and diecasting machine can be detached from the machine for IUT fabrication. Two LN/PZT IUTs were then fabricated onto this steel pipe at two opposite cylindrical convex sides facing each other, as shown in Fig. 3. This configuration could allow the use of transmission as well as reflection mode operation during process monitoring.

In order to simulate on-line monitoring at the nozzle, the pipe with LN/PZT IUTs in Fig. 3 was filled with silicone oil and ultrasonic measurement was performed in transmission mode. The result is shown in Fig. 4. The transmitted signal through silicone oil was clearly observed at 200°C. The real-time non-invasive process monitoring of thixomolding and Al diecasting at the nozzle is being prepared and the results will be reported in future.



Fig.3 LN/PZT IUTs onto a steel pipe.

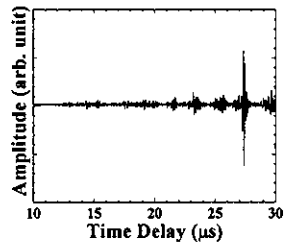


Fig.4 Transmission mode of Fig. 3 with oil at 200°C

4. BIT/PZT IUTs onto a mold insert

Filling completion monitoring has been demonstrated in [1] using the invasive and bulky delay line probes installed in the die. One objective of this study is to develop an on-site fabrication technique to deposit the non-invasive and miniature HT IUTs onto a large size metallic mold insert, e.g. of thixomolding machine for process monitoring purposes. It is noted that a large size mold insert has huge thermal capacitance, it needs great care to develop heating and cooling methods as well as electric poling technique to treat the sol-gel

fabricated piezoelectric composite films.

Since the temperature of mold insert as shown in Fig. 5 is lower than 450°C, BIT/PZT IUTs were chosen. The dimensions of this die are of 46cm width, 61cm length and 5cm height, respectively. Several BIT/PZT IUTs were fabricated onto the mold insert. The ultrasonic performance of the IUT fabricated onto the surface is shown in Fig. 6. The 1st, 2nd, and 3rd reflected round-trip echoes represented by L¹, L² and L³, respectively through the thickness of the die were clearly observed. The center frequency, 6dB bandwidth and SNR of the L¹ echo are 11.9MHz, 15.4MHz and 31dB, respectively. It is believed that BIT/PZT IUTs are suitable for process monitoring of thixomolding and diecasting at the mold insert and the die.

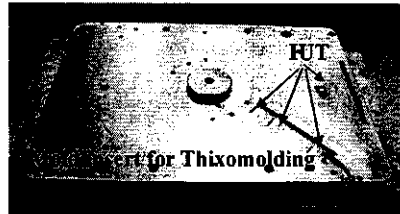


Fig. 5 BIT/PZT IUTs fabricated onto a mold insert for Mg thixomolding machine.

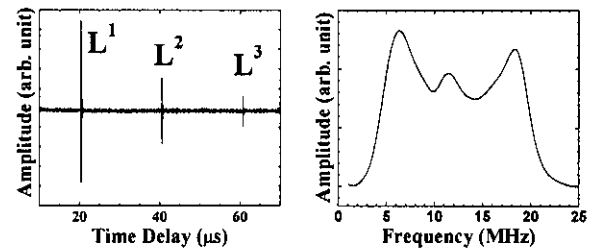


Fig. 6 Ultrasonic performance of BIT/PZT IUT fabricated onto the surface of a thixomolding mold.

5. Conclusions

800°C LN/PZT [3] and 450°C BIT/PZT IUTs [2] were fabricated onto a titanium substrate and a steel pipe, and a thixomolding mold insert, respectively by a sol-gel spray technique suitable for on-site fabrication. The ultrasonic measurement results indicated that these IUTs are suitable for real-time non-invasive ultrasonic process monitoring at the nozzle and die of thixomolding and die casting machines.

References

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