NOVEL METHODS FOR CRACK DETECTION IN GREEN AND SINTERED PARTS

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ABSTRACT. Crack detection in unsintered, or green, powder metal parts has been of interest for decades with no commercial solution available. Traditional ultrasonic techniques using liquid couplant cannot be used with green parts since residue left behind from the couplant will degrade the final quality of the sintered part. In this paper, two couplant free techniques are presented for the inspection of green and sintered parts. The surface wave mediator technique uses point contact with a part to induce and receive Rayleigh surface waves which are sensitive to surface breaking cracks and density variations. The mediator tip can be shaped to effectively inspect both flat and curved geometries such as boreholes. Feasibility studies performed using ultrasonic electromagnetic acoustic transducers (EMATs) on both green and sintered parts have been successful in impinging ultrasonic energy into the parts for defect detection. Due to the low aspect ratio of many powder metal parts, ultrasonic guided waves can provide full part characterization. Shear horizontal waves were used to inspect the flange of a transmission part and torsional waves have been used to inspect the welded region of a sintered porous filter.

Keywords: green part, surface wave mediator, ultrasonics, electromagnetic acoustic transducer, torsional wave
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INTRODUCTION

Cracks in green parts are formed either during ejection after compaction or during handling [1-2]. Detecting cracked green parts prior to sintering can eliminate additional processing on an otherwise bad part. Many traditional NDE techniques use coupling media, which can potentially contaminate green parts, thus affecting the final sintered part's properties. A new ultrasonic technique utilizing Rayleigh waves can detect surface and subsurface breaking cracks, density gradients, and crack orientation [3-5]. This local inspection technique induces ultrasonic energy into a part through a small contact area without coupling media. Some sintered parts require inspection without a coupling media based on contamination problems. Compared with other ultrasonic NDE testing methods, electromagnetic acoustic transducers (EMATs) can induce waves in conductive materials without couplant and provide global part inspection for both green and sintered parts.

SURFACE WAVE MEDIATOR PROBE THEORY

A surface wave mediator probe consists of three components: a normal beam piezoelectric transducer, a Plexiglas wedge, and a steel mediator. At the interface between the plexiglas wedge and steel mediator, mode conversion occurs as the longitudinal wave is

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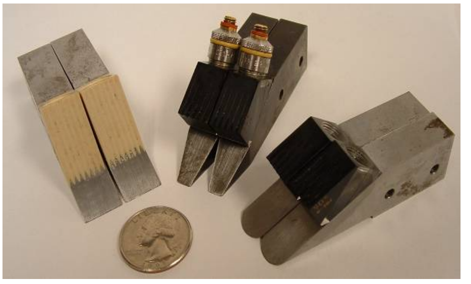


FIGURE 1. Surface wave mediator probes with different tips to match part geometries.

refracted into a Rayleigh wave. Calculation of the critical angle for the wedge in which mode conversion occurs is done using Snell's Law: as shown in Equation 1.

$$\frac{C_{L,plexiglas}}{\sin\theta} = \frac{C_{R,steel}}{\sin 90^0} \tag{1}$$

Using the longitudinal wave velocity of Plexiglas and the Rayleigh wave velocity of steel, the third critical angle is obtained as 66º. The surface wave in the steel mediator is transmitted to the green part at the mediator tips through Hertzian contact loading. A variety of mediators are shown in Figure 1. The surface wave mediator fixture employs a through transmission setup [4], and was developed to position the mediator probes on a variety of multilevel part geometries such as the base of a step and O-ring groove [5].

PART INSPECTION USING ROUNDED MEDIATOR TIPS

A rounded mediator tip can eliminate alignment problems and can be used to detect the cracks in circular geometries as shown in Figure 2. The resultant ultrasonic waveforms and FFT analysis of the respective gated regions for a defect-free part and a cracked part section are shown in Figure 3. The results show that signals from cracked parts have a decrease of amplitude in the time and frequency domain. The amplitude ratios of two peak frequencies are different between a defect-free part and a cracked part.

(a) (b)

FIGURE 2. (a) Experimental setup for testing of a flat part with point contact. (b) Experimental setup for testing a specimen with a borehole.

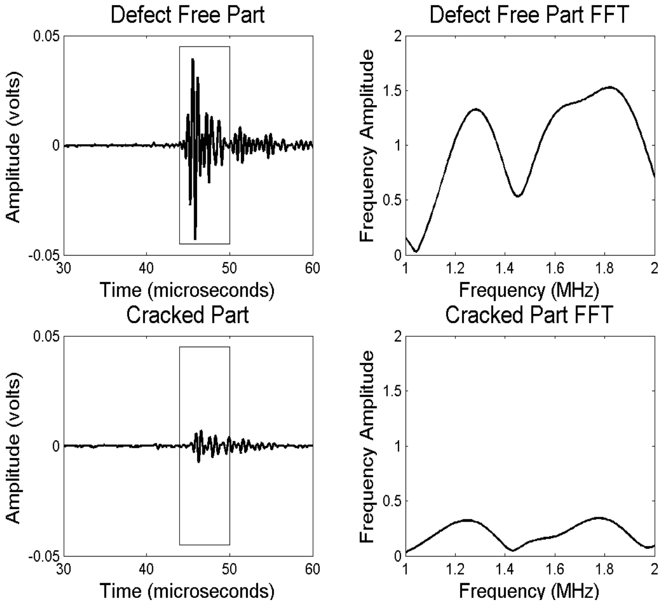
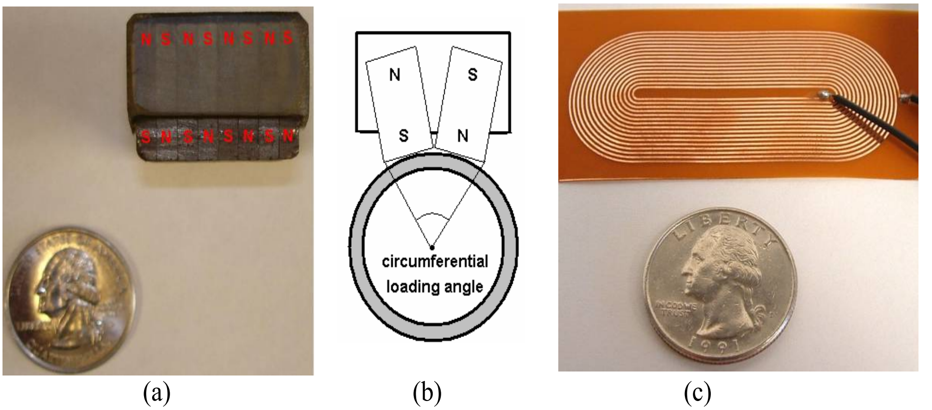


FIGURE 3. Ultrasonic waveforms and FFT analysis of the respective gated regions of a defect free part and a cracked part.

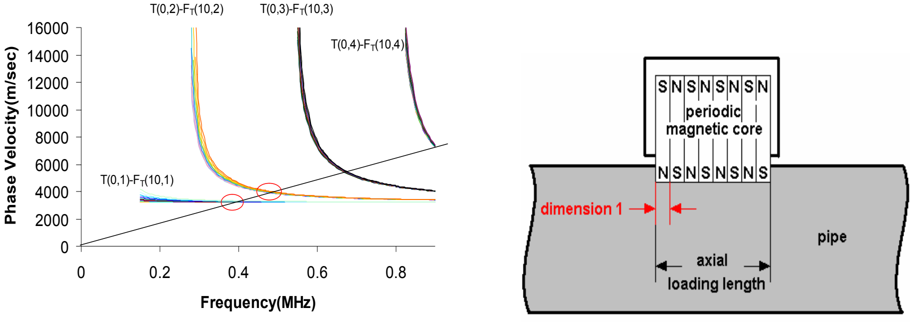
EMAT TESTING OF SINTERED POROUS MEDIA

EMATs can be constructed to excite and receive a wide variety of bulk and guided ultrasonic waves used to detect sub-surface cracks and defects. EMATs eliminate variations, such as contact pressure and wetting, associated with liquid couplant inspection thus resulting in uniform inspection between specimens. Ultrasonic energy can be induced into a part regardless of surface roughness. Torsional waves generated by horizontally polarized shear wave EMATs are sensitive to defects in welded sections of the hollow cylindrical filters. Figure 4 shows the components of the Shear Horizontal EMATs used in the experiment.



(a) (b) (c)

FIGURE 4. Shear Horizontal EMAT components: (a) SH wave EMAT periodic magnetic core, (b) the magnets in the core are angled to fit the curvature of the pipe, and (c) SH wave EMAT faceplate, which is a copper etch on a Mylar substrate.



(a) (b)

FIGURE 5. (a) The excitation line of the dispersion curves indicates mode generation possibilities in a pipe. (b) The slope of the excitation line is based on the thickness of a periodic magnet in the magnetic core.

The specimen in the experiment is a cylindrical sintered porous filter which can be modeled as a pipe. According to the pipe theory, there are two group mode types: axisymmetric and non-axisymmetric modes [6]. Signals received from transducers placed 180 degrees apart from each other with respect to the circumference of the filter show that partial loading (non-axisymmetric modes) could be used to inspect the entirety of the weld circumference. Based on the phase velocity dispersion curve, many modes can be generated. Figure 5 shows the excitation of the non-axisymmetric modes.

Transmitting and receiving matching networks were used to impedance match the pulsing and receiving equipment to the filters. The setup shown in Figure 6 is used for crack detection in the sintered porous filters. Tone burst wave generation was used to drive transducers with a spacing of 0.25 in (6.35mm) at a frequency of 400 kHz. A sample signal is shown in Figure 7.

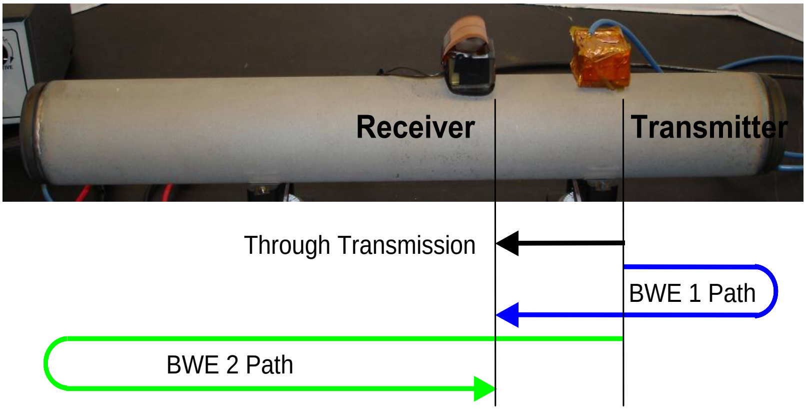


FIGURE 6. The inspection setup for testing flange welds in sintered porous filters. The wave paths are shown for the Through Transmission and BWE (Back Wall Echo) signals.

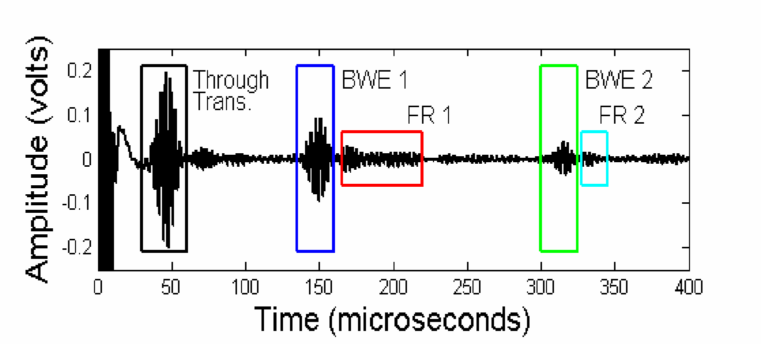
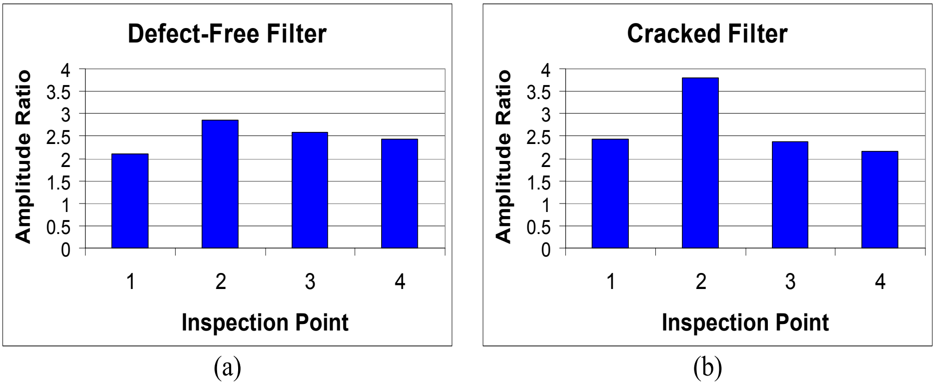


FIGURE 7. Resultant ultrasonic waveform from a weld inspection. "FR" represents the Flange Reflection signal.

Each filter was inspected at four points along the circumference 90º apart. The received ultrasonic signal was analyzed for weld uniformity and weld quality. Weld uniformity was measured by using amplitude ratio of through transmission signal versus back wall echo signal thus providing self-calibration. Figures 8 and 9 show a crack-free filter and a cracked filter and the weld uniformity results, respectively. The difference between the maximum and minimum amplitude ratio for weld uniformity was calculated to be 0.49 for the good filter and 1.65 for the bad filter. The threshold values set after testing multiple filters was 0.6.

(a) (b)

FIGURE 8. (a) A defect free part and (b) a cracked filter. Note the difference in the weld.



(a) (b)

FIGURE 9. Amplitude ratios of through transmission signal versus back wall echo signal for a good filter (a) and a bad filter (b).

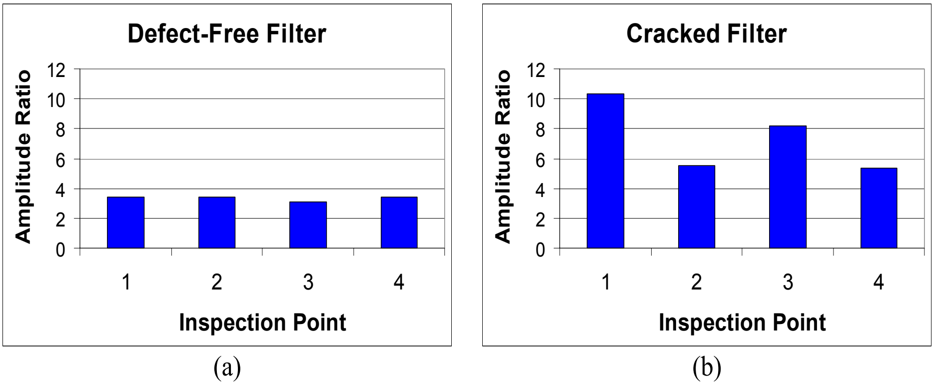


FIGURE 10. The amplitude ratios of BWE 1 over the Flange Reflection 1 at four points for a good filter (a) and a bad filter (b).

Weld quality was measured by the amount of ultrasonic energy escaping into the flange beyond the back wall echoes. An amplitude ratio of BWE 1 versus Flange Reflection 1 was calculated for the inspection points as shown in Figure 10. The maximum amplitude ratio for weld quality was found to be 3.45 for the good filter and the 10.33 for the bad filter. The threshold values set after testing multiple filters was 4.0. The following trend was observed: the lower the amplitude ratio, the better the weld quality. Comparing the ratios of four points for each filter, the difference between the maximum and minimum amplitude ratio is 0.38 for the good filter and 4.98 for the bad filter. This result also shows there is a crack in the bad filter. All results were verified with a pressurized bubble test of the welds.

GREEN "RING FLANGE" FEASIBILITY STUDY

The goal of this feasibility study was to be able to detect defects in green parts using EMATs. For these tests, a green "Ring Flange" part was chosen which is susceptible to damage during handling. Two defects, a drilled hole and a filed groove are shown in Figure 11 along with the corresponding ultrasonic waveforms compared with the defect free sample. For these tests, tone burst wave generation was used to drive transducers with a spacing of 0.25 in (6.35mm) at a frequency of 400 kHz. The results show that after inducing the defects, the amplitude of the wave packets decreased 1.08 dB for the groove and 1.24 dB for the drilled hole. Time delays of 0.7 μs and 2.2 μs were measured for the groove and the drilled hole, respectively. Figure 12 shows chipping of the flange along with the corresponding ultrasonic waveforms compared with the defect free sample. The result also shows that there is a large decrease in amplitude of 9.90 dB and significant time delay of 38.3 μs.

Permanent magnetic core EMATs can be used on green parts if the strength of the magnetic field is less than the mechanical bonds between the compacted particles. This testing shows that guided waves can provide full part characterization of green parts by inspecting the entire circumference of the ring flange.

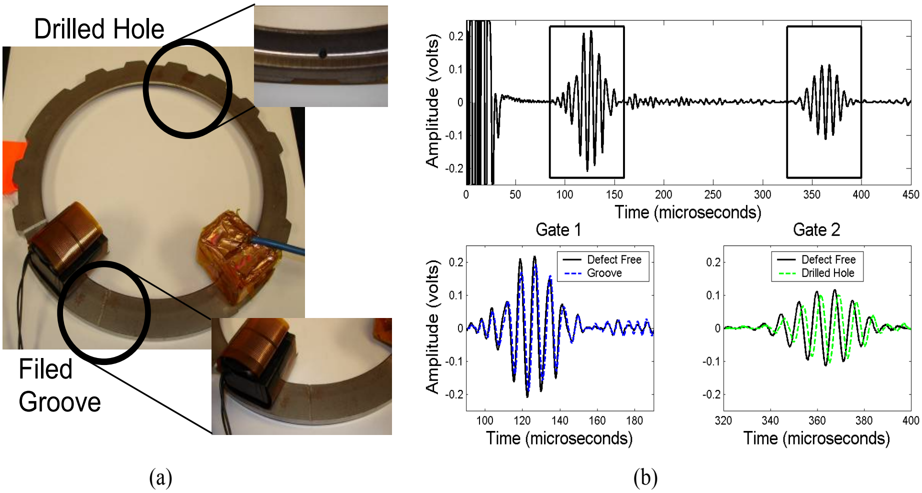


FIGURE 11. (a) The "Ring Flange" and the induced defects. (b) Ultrasonic waveforms of the gate 1 and gate 2 for defect free flange and cracked flange along with the filed groove and drilled hole, respectively.

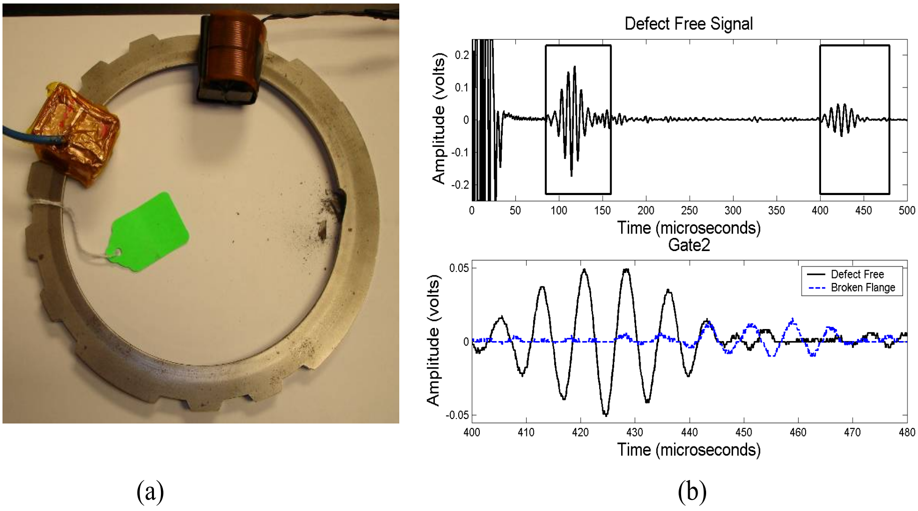


FIGURE 12. (a) Damaged flange and (b) ultrasonic waveform comparing the defect free flange to the damaged flange.

CONCLUSION

The surface wave mediator technique is an efficient way to detect defects in green parts with different geometries including multilevel parts. The mediator tips can be shaped to fit specific part geometries, such as the rounded mediator tips which fit boreholes. EMATs also can provide global inspection of sintered porous media and green parts. Weld uniformity and weld quality of the sintered porous media can be obtained by signal analysis. Furthermore, in order to detect the defects in green parts, three kinds of induced defects on a "ring flange" have been studied by analyzing the change of amplitude and time delay.

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