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Ultrasonic isolation of buried pipes

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ABSTRACT

Long-range guided wave testing (GWT) is used routinely for the monitoring and detection of corrosion defects in above ground pipelines. The GWT test range in buried, coated pipelines is greatly reduced compared to above ground configurations due to energy leakage into the embedding soil. In this paper, the effect of pipe coatings on the guided wave attenuation is investigated with the aim of increasing test ranges for buried pipelines. The attenuation of the T(0,1) and L(0,2) guided wave modes is measured using a full-scale experimental apparatus in a fusion-bonded epoxy (FBE)-coated 8 in. pipe, buried in loose and compacted sand. Tests are performed over a frequency range typically used in GWT of 10–35 kHz and compared with model predictions. It is shown that the application of a low impedance coating between the FBE layer and the sand effectively decouples the influence of the sand on the ultrasound leakage from the buried pipe. Ultrasonic isolation of a buried pipe is demonstrated by coating the pipe with a Polyethylene (PE)-foam layer that has a smaller impedance than both the pipe and sand, and has the ability to withstand the overburden load from the sand. The measured attenuation in the buried PE-foam-FBE-coated pipe is found to be substantially reduced, in the range of 0.3–1.2 dB m^{-1} for loose and compacted sand conditions, compared to measured attenuation of 1.7–4.7 dB m^{-1} in the buried FBE-coated pipe without the PE-foam. The acoustic properties of the PE-foam are measured independently using ultrasonic interferometry and incorporated into model predictions of guided wave propagation in buried coated pipe. Good agreement is found between the experimental measurements and model predictions. The attenuation exhibits periodic peaks in the frequency domain corresponding to the through-thickness resonance frequencies of the coating layer. The large reduction in guided wave attenuation for PE-coated pipes would lead to greatly increased GWT test ranges; such coatings would be attractive for new pipeline installations.

1. Introduction

The abundance of pipelines worldwide requires the use of inspection technologies to facilitate integrity management for early detection of corrosion and possible leakage locations. Elastic wave propagation along cylindrical shells has received comprehensive treatment in the literature, e.g. [1–5] and has been utilised successfully in non-destructive evaluation for the inspection of pipelines [6–11]. The long-range guided wave testing (GWT) method has been routinely used for over a decade in the petrochemical, energy and nuclear industries [12–15]. GWT offers rapid screening of pipework for the detection and monitoring of corrosion defects from a single transducer position. The method typically employs torsional (T(0,1)) or longitudinal (L(0,2)) wave

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modes in frequencies below 100 kHz. Waves are excited and received either using a transducer ring comprising an array of dry-coupled piezoelectric elements equally spaced around the circumference of the pipe [10,16–20] or magnetostrictive sensors, e.g. [21,22]. The method is commonly applied to bare- or thinly epoxy-painted pipes in above-ground configurations, where a single transducer ring location provides coverage of several tens of metres, e.g. [12]. However, for pipes buried in soil test ranges are drastically reduced [15,23]. Typically for modern pipeline engineering practices, coating materials, e.g. fusion-bonded epoxy (FBE), coal-tar-enamel and high-density polyethylene (HDPE), are either factory- or field-applied to pipes that are buried in the ground in order to provide insulation from harsh environments and protection from corrosion. The guided wave attenuation in coated or embedded waveguides is due to leakage of energy radiating out into the embedding material, and damping by energy-absorbing materials of the waveguide system, resulting in a severe reduction of the test range. The extent of leakage depends on the material properties of both the pipe and the embedding material. For structures coated with materials having internal damping, e.g. bitumen, the attenuation is also related to the fraction of energy in the mode of interest that is carried in the coating layer and generally increases with frequency.

Wave propagation in multi-layered systems has been described in the literature in the context of geophysics and acoustics e.g. [24–26]. Matrix techniques (e.g. [27] and references therein) have been used for embedded and coated waveguides to yield dispersion curves and through-thickness wave mode-shapes for certain regular geometries, i.e. flat plate and cylindrical structures. These were used to evaluate the guided wave mode properties, including attenuation and sensitivity to target defect morphologies [27,28]. Leaky cylindrical waveguides embedded in infinite media were studied in several configurations, including steel bars embedded in cement grout [29], rock bolts embedded in rock strata [30], reinforcing bars and anchor bolts embedded in concrete [31], steel bars embedded in soil [32], and wires in epoxy resin [33,34]. Wave propagation in attenuative viscoelastic materials was treated rigorously for plastic plates [35,36], elastic plates coated with viscoelastic materials [37–39], and elastic hollow cylinders coated with viscoelastic material externally [40] and internally [41]. Finite-element modeling and semi-analytical finite-element formulations were utilised to address coated pipes [42–45] and coated pipes buried in soil [46,47], as well as the general case of arbitrary section waveguides embedded in solid media [48]. Only limited measurements of the torsional guided wave attenuation in buried pipes have ever been reported in the literature [49]. Recently, Leinov et al. [23,50] studied systematically guided wave propagation in a bare steel pipe buried in sand under a variety of experimental conditions and examined the nature of the attenuation of the modes, which is primarily due to leakage of energy.

Buried pipelines are currently accessed for GWT by digging a pit to expose the pipe at the location where a transducer ring is to be attached (Fig. 1). A very large fraction of the costs involved in GWT of such buried-pipe systems is in gaining access to attach the transducer ring and re-covering the pipeline after the inspection. Hence, maximizing the distance over which the guided waves can propagate and defects can be detected from a single access location is essential and has substantial economic implications.

In the present study, we investigate guided wave propagation in buried FBE-coated pipe using a full-scale experimental apparatus and model simulations. Measurements of torsional and longitudinal guided wave mode attenuation are compared to an earlier investigation performed by the authors on bare pipe buried in sand [23]. We aim to investigate the effect of the pipe coating on the guided wave attenuation and to determine whether a pipe coating can be used to increase the test range in buried pipelines. Ultrasonic isolation of a buried pipe is demonstrated by utilising a low impedance coating material which effectively decouples the influence of the sand on the ultrasound leakage from the buried pipe. The acoustic

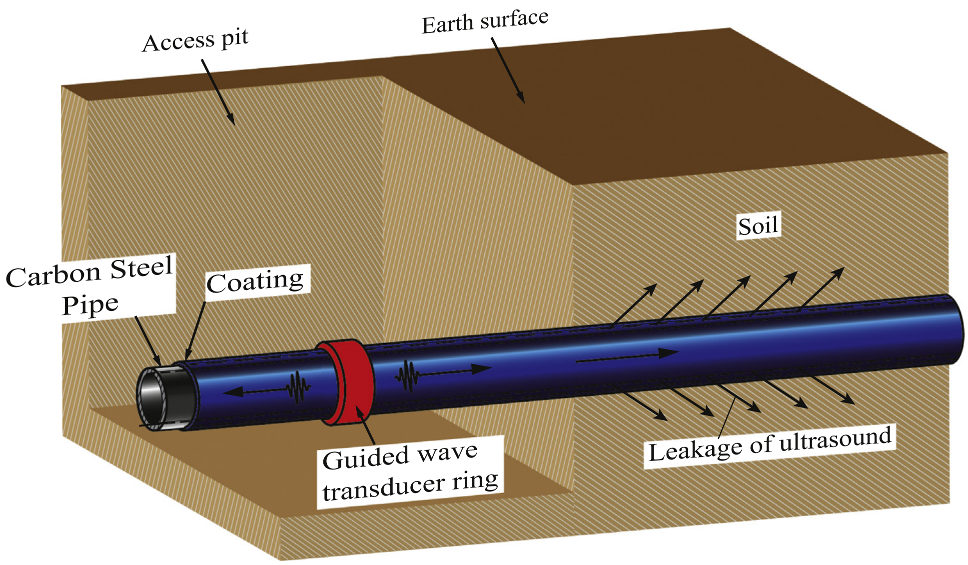

Fig. 1. Schematic of a coated pipe buried in soil. An access pit is excavated in order to perform guided wave inspection, where a guided wave transducer ring is attached to the pipe.