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Attenuation of Guided Wave Propagation by the Insulation Pipe

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1. Introduction

Pipeline systems are widely used in gas, refinery, chemical and petro-chemical industries, which usually carry high pressure, high temperature or even highly corrosive fluids. Cracks and corrosion are often found at the outer or inner surface of pipeline and can lead to a serious thinning of wall thickness. Leaks or sudden failures of pipes can cause injuries, fatalities and environmental damage. Ultrasonic nondestructive techniques are available for the detection of wall loss associated with defects in the pipe. Unfortunately, a high proportion in pipelines of these industrial are insulated, so that even external corrosion cannot readily be detected by the conventional ultrasonic testing (single position measurement) without the removal of the insulation, which in most case is time-consuming and cost expensive. Especially in typically industrial plants, there are hundreds of kilometers of pipelines can be in operation. Making inspection of full pipelines is virtually impossible in industrial plants. There is therefore a quick reliable method for the detection of corrosion under insulation (CUI). This technique, called guided wave, employs a pulse-echo system applied at a single location of a pipe where only a small section of insulation need to be removed, using waves propagation along the pipe wall. The changes in the response signal indicate the presence of an impedance change in the pipe. The shape and axial location of defects and features in the pipe are also determined by reflected signals and their arrival times. Propagation distance of many tens of meters can readily be obtained in steel pipes [1-6]. Since these guided waves are cylindrical Lamb waves along the pipe, no lateral spreading can occur and the propagation is essentially one-dimensional. In a uniform pipe, their amplitude with propagation distance is therefore only reduced by the material attenuation of the steel [7].

However, many pipes of interest are necessary wrapped with the coated materials for manufacturing process in refinery, chemical and petro-chemical plants. When the pipe is coated, some energy from the guided wave in the pipe wall can leak into the insulation material and the wave attenuates as it goes along the pipe, thus reducing the wave propagation distance. The rate of energy leakage depends on the wave propagating mode in the pipe, on the acoustic impedance and attenuation properties of the insulation material [8]. The insulation material like a mineral wool has very low acoustic impedance and is not strongly adhered to the pipe. So it has virtually no effect on either the torsional or longitudinal wave. However, if the pipe is coated by a heavy viscous substance such as bitumen, epoxy, then both shear and longitudinal modes can leak from the pipe. The rate of leakage is then controlled by the properties and thickness of the coating, the displacement of the pipe surface in all direction (radial, circumferential and axial) and the frequency. This paper describes an investigation of the attenuation of a guided wave propagating on the pipe due to various coated materials such as mineral wool, polyethylene, and bitumen which are typically used to insulate the pipeline in industrial plants. The effect of reflected signals and the traveling distance of guided waves are demonstrated both on analytical predictions and experimental measurements for a variety of the coated materials on the pipe.

There have been few studied on this subject. However, Lowe and Cawly [9] considered the plate of adhesive and diffusion bonded joints to study the leakage of energy by both longitudinal and shear wave which leads to very high attenuation rates, especially when the acoustic impedance of the materials mismatch highly between another. This case is similar to the case of a pipe embedded in a solid. Wave propagation studies in structural composites are of relatively similar [10,11]. Since the composite laminates used in aircraft and aerospace structures are usually thin plate. They have been developed in an effort to gain model-based understanding of the nature of the guided waves that can be transmitted in the composite thin plates. Jones and Laperre [12,13] also considered the propagation of Lamb waves in bi-layered elastic plates, but they did not explore the effects of internal losses. More recently, the internal losses in the coating are modeled according to the theory of linear viscoelasticity by Simonetti [14]. He found that at low frequency the guided wave attenuation is only slightly affected by the longitudinal bulk attenuation, while the contribution of the shear bulk attenuation is substantial. However, while internal losses in metals are negligible at the low frequency used, the presence of attenuate media in combination with the propagation wave can dramatically attenuate the energy of guided wave. Since a significant proportion of industrial structures are coated or embedded in other material, the assessment of the attenuation characteristics of the propagating wave modes becomes a major issue. The attenuation of the torsional guided wave in a Coal-tar-enamel-Coated pipe was measured by Kwun [15]. He used torsional guided wave to measure the attenuation of buried pipe which is coated the Coat-tar-enamel material. However, no information is currently available on the effect of the coated material on the pipe when a guided wave is employed for pipeline inspection. The aim of this paper is to evaluate the attenuation of the industrial designation coated material on the pipe when the guided wave is traveling in the pipe.

2. Materials

Since the pipe is coated with a viscous material and the energy can be carried away from the pipe by both shear and compressional waves, there is a need to analyze the wave structure under energy attenuation. The wave structure describes the displacement pattern of the propagation mode for different frequencies across the thickness of the pipe. However, the wave structure of the torsional T(0,1) mode is not frequency dependent due to its completely non-dispersive characteristics at all frequencies. The wave structure of T(0,1) mode in a 6 inch steel pipe is shown in Fig.1. It shows the profile of the tangential displacement through the thickness of the pipe wall. The axial and radial displacements are zero in this mode. It can be seen that the tangential displacement are approximately constant through the wall thickness. It is also indicated that defects can be detectable anywhere in the cross section of the pipe as illustrated at 28 kHz in Fig.1, since the T(0,1) mode is a constant with frequency. An example of the wave structure for various coated material at frequency 28 kHz are also shown in Fig.2. These plots represent the amplitudes of the circumferential displacement from the centre line of pipe of the outer half space, i.e., through the inner of pipe, then through the pipe wall, and finally through the coated material layer. For the T(0,1) mode, the circumferential displacement through the coated material layer is dominant, since the inner of pipe is empty [16]. When the pipe is coated with the strong adhesive material, such as bitumen (Fig.2a), and with the weak adhesive material, such as polyethylene (Fig.2b), the energy of guided wave will leak into the coated material from the pipe wall. The rate of leakage is controlled by the strength of adhesion on the pipe and the frequency of propagation mode. If the pipe is coated with the insulation material, such as mineral wool (Fig.2c), it is not adhered to the pipe, and then the amplitude of circumferential displacement decreases in the pipe with distance due to the material properties of pipe. This T(0,1) mode and 6 inch steel pipe are also used in the experimental measurements for the results comparison.

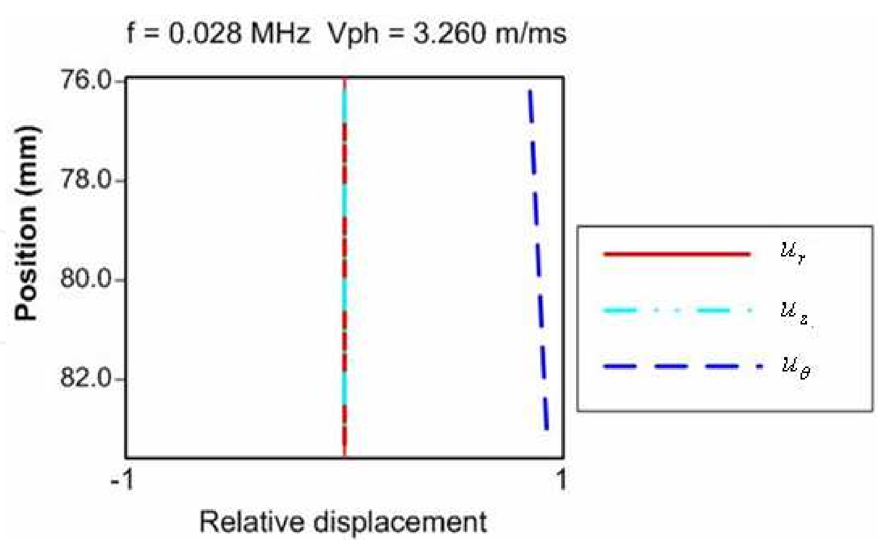
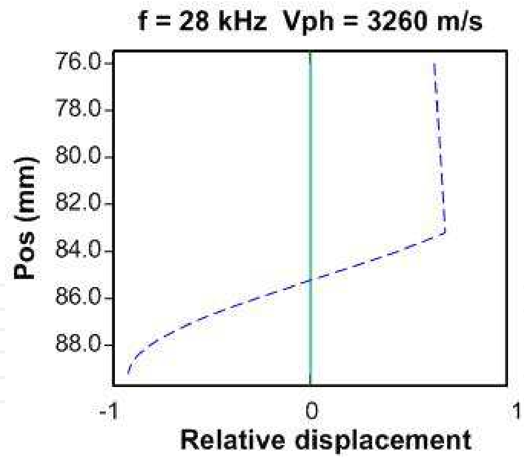
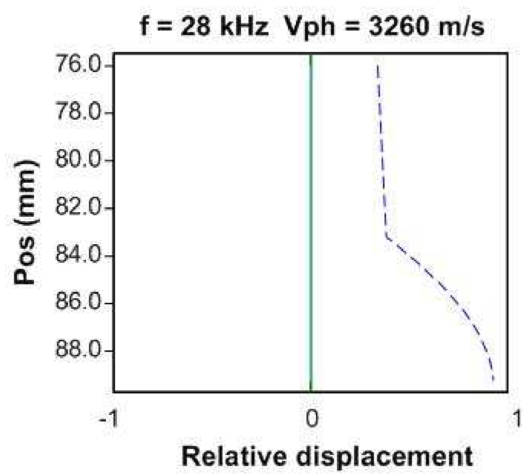


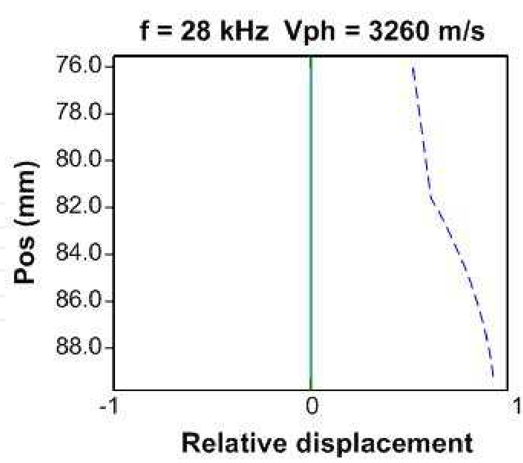
Fig. 1. The wave structure of T(0,1) mode in a 6 inch pipe at 28 kHz. This profile shows the relative displacements from inside wall 76 mm to the outside wall 83.2 mm. The radial displacement u_r and axial displacement u_Z are zero.



(a) bitumen



(b) polyethylene



(c) mineral wool

Fig. 2. The wave structures of various coating materials at frequency 28 kHz; (a) for bitumen coating, the amplitude of circumferential displacement is vary from the inside wall (position 76 mm) to outside wall (position 83.2 mm) then through the coating material. The relative displacement changes significantly high in the viscous layer; (b) for polyethylene coating, the variation of the relative displacement is slightly high in the viscous layer. (c) for mineral wool coating, its relative displacement is near the same as in the viscous layer.

The coated material used on the pipe is usually a viscoelastic layer adhered on the pipe. The internal losses in the coated material are modeled according to the theory of linear viscoelasticity, which is also the model implemented in the software DISPERSE [17] used for the wave structure analysis. The shear velocity and shear attenuation of bitumen are obtained from the result of Simonetti measurement [16] for the software used to predict the attenuation of guided wave. The material properties of the other two coated materials are found from the data bank in the DISPERSE software. The theory of linear viscoelasticity for isotropic and homogenous media is modeled in the frequency domain, which leads to linear equation of motion [18]. Thus

$$(\tilde{\lambda}+\tilde{\mu})\nabla(\nabla \bullet \vec{u})+\tilde{\mu}\nabla^2\vec{u}+\rho\omega^2\vec{u}=0 \tag{1}$$

Where $\vec{u}$ is the Fourier transformed displacement vector, ρ is the density of material, ∇ is the three dimensional differential operator and ω is the angular frequency. The complex frequency dependent functions $\tilde{\lambda}$ and $\tilde{\mu}$ are related to the relaxation functions of the material $\lambda(t)$ and $\mu(t)$.

$$\tilde{\lambda}=\lambda_0+i\omega\int_0^\infty \lambda(t)e^{i\omega t}dt \tag{2}$$

$$\tilde{\mu}=\mu_0+i\omega\int_0^\infty \mu(t)e^{i\omega t}dt \tag{3}$$

Where λ_0 and μ_0 are the asymptotic values of the relaxation curves.

Simonetti [14] studied the relationship among the guided wave attenuation, the strain energy in the viscoelastic layer, and the acoustic properties of the coated layer. For the case of torsional mode, it has already been shown [19] that by considering a volume, V, of one cycle in the circumferential direction (2π r), and with height equal to the thickness of the coated layer, the guided wave attenuation, α, can be related to the average dissipated power, P_d, in the volume and the average in-plane power flow, $<P>$, [14]

$$\alpha=\frac{dP_d/dz}{2<P>} \tag{4}$$

Where z is the axial direction of pipe.

Generally speaking, at the considered portion of a viscoelastic medium, the average dissipated power per unit volume can be related to the peak strain energy per unit volume [20]. As a result, the total attenuation in volume, V, for the guided wave can be expressed as [14]

$$\alpha=\frac{1}{2}\omega\frac{\tilde{u}_i}{\tilde{u}_r}\frac{dE/dz}{<P>} \tag{5}$$

Where the subscript i refers to the imaginary part of the quantity, and r refers to the real part of the quantity. E is the peak strain energy of the portion of the viscoelastic layer contained in V. There are two different material attenuation regimes can be defined in

Equation (5). When the material attenuation is low which is accompanied by small imaginary parts of the Lame constant, the viscoelastic layer embraces both the non-propagating and propagating branches of the corresponding elastic layer. It will disperse in the phase velocity and guided wave attenuation spectra. For the material attenuation is high which is representative of steel pipe coated with bitumen, the energy of guided wave is employed into two parts. The first one travels primarily in the elastic layer and the second one is trapped in the viscoelastic layer. While the energy of the second family have little practical interest, as they are highly attenuated with distance, the energy of the first family can be employed in suitable frequency ranges.

3. Experimental setup

All the experiments have been performed on a 6-inch schedule 40 steel pipe, which is usually used in refinery and petro-chemical factories, to measure the reflected signal of the torsional T(0,1) mode. The pipe has three flanges, two bends, one branch, one welded support, one simple support, one patch, and ten welds of features on it. Fig.3 shows the positions of various features on the experimental pipe. The flange is assumed to be a 100% reflector, since it breaks all of the energy in the guided waves and this signal is the level of the outgoing guided wave. At a bend the geometry of the pipe changes and the pipe is no longer symmetric about the plane normal to its axis. The major characteristics of the bends are the reflected signal from the two closely spaced welds, but there will some mode conversion caused by the change in geometry of the pipeline at the bend. The branch has a side outlet hole at right angles to the axial run of the pipeline. This hole, which changes in geometry, produces direct and mode converted reflected signals. The response from this branch is similar to a bend with two closely spaced weld reflected signals. The welded support is a bracket welded to the pipe over a significant axial length. The response from this welded support is complicated due to mode conversion. The amplitude of reflected signal from welded support depends on the length of the support. The clamped support is a U type of clamp. The reflection from clamped support depends on the tightness of clamp and the frequency of excitations. The patch is similar to a defect that extends in the axial direction order more than 1/4 of a wavelength. It generates reflections from the front and back of the patch. The reflected signals are the combination of the front and back of the reflections. In general, the weld is a symmetric geometry of pipe. The weld caps cause a geometric change in the pipe wall section, which also reflects the guided wave. The amplitude of the reflected signal is related to the percentage increase in the wall cross-section at the weld. The reflected signals from various features on the experiment at frequency regime 1.0 are shown in Fig.4. The frequency regime is introduced instead of frequency in the system since the behavior of the guided waves propagation in the pipe varies with pipe dimensions. It is defined as a number which normalizes the wavelength to pipe diameter. In Fig.4, the horizontal axis is the distance from the position of the transducer mounted on the test pipe. The vertical scale is the reflected amplitude in millivolts. The gray area in Fig.4 is the near field of transducer. The amplitude of the reflected signal in this near field cannot be measured for calculation. The green area in Fig.4 is the dead zone of the measuring distance. This dead zone is near the transducer that cannot be inspected. The –W1 and +W1 sign shown in Fig.4, represent the location of the welds where the distance are

2.5-m and 3.5-m from the transducer, respectively. The amplitude and shape of the reflected signals of the weld do not change with frequency. That is why the amplitude of the reflected signal of the weld is measured for comparison standard in this paper. The differences in the amplitudes of the individual welds, -W1 and +W1 sign, indicate the variation in size of the weld caps. The –N1 and +N1 signatures in Fig.4 are the location of artificial defect which are 3.6-m and 4.9-m from the transducer, respectively. Most defects are non-symmetric. The position of these reflected signals are generally suspected as indicating anomalies, with the shape of defect signature distorted from peak shape. The amplitude of the reflected signal from defect is dependent on the depth and circumferential extent of the defect. The position of –P1 in Fig.4 is the patch feature which locates at 4.7-m from the transducer. The –F1 sign shown in Fig.4 represents the location of the flange where the distance is 6.0-m from the transducer. The shape of the flange signature depends on the duration of the excitation signal and the geometry of the flange. No energy is propagated across flanges, and testing is only possible between flange breaks. The +E1 signature in Fig.4 is the location of elbow of pipe which is 6.35-m from the transducer. The dashed lines, which indicate exponential decay, represent the distance amplitude correction curves from the features of the flange, weld and noise, respectively.

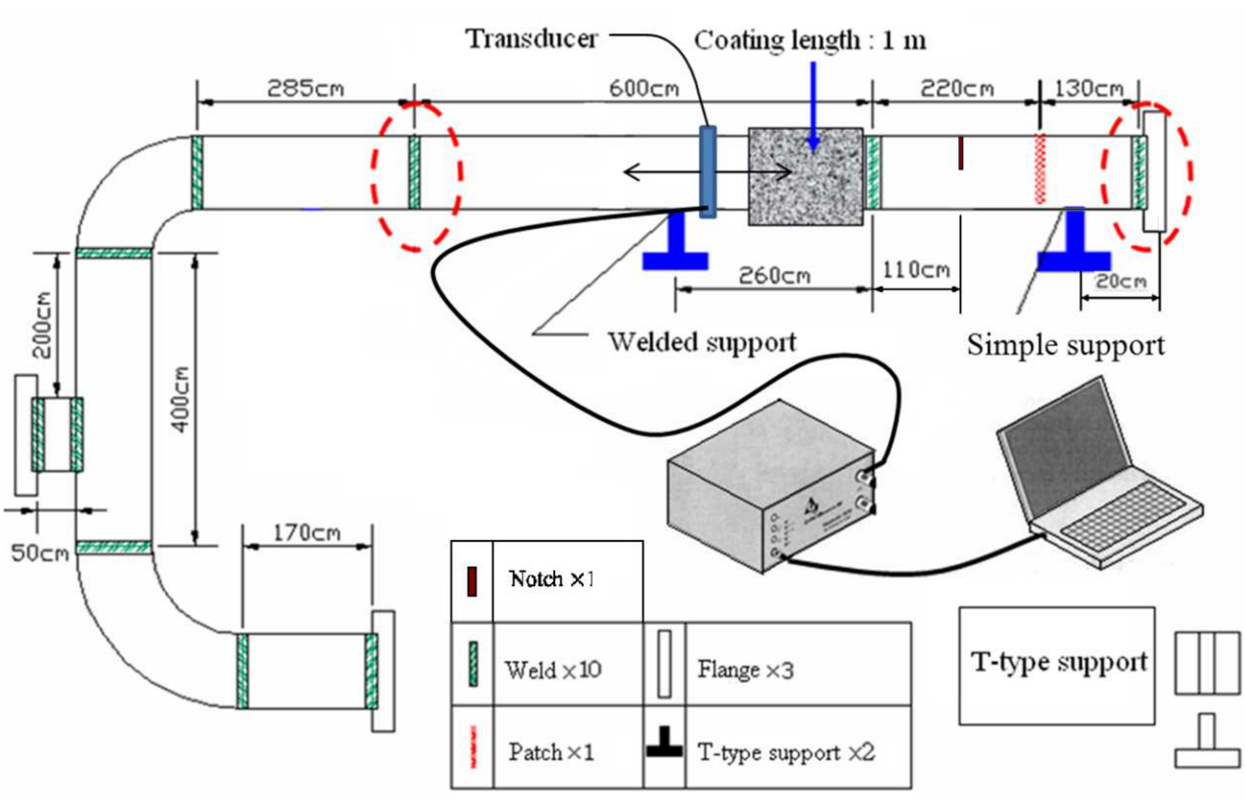
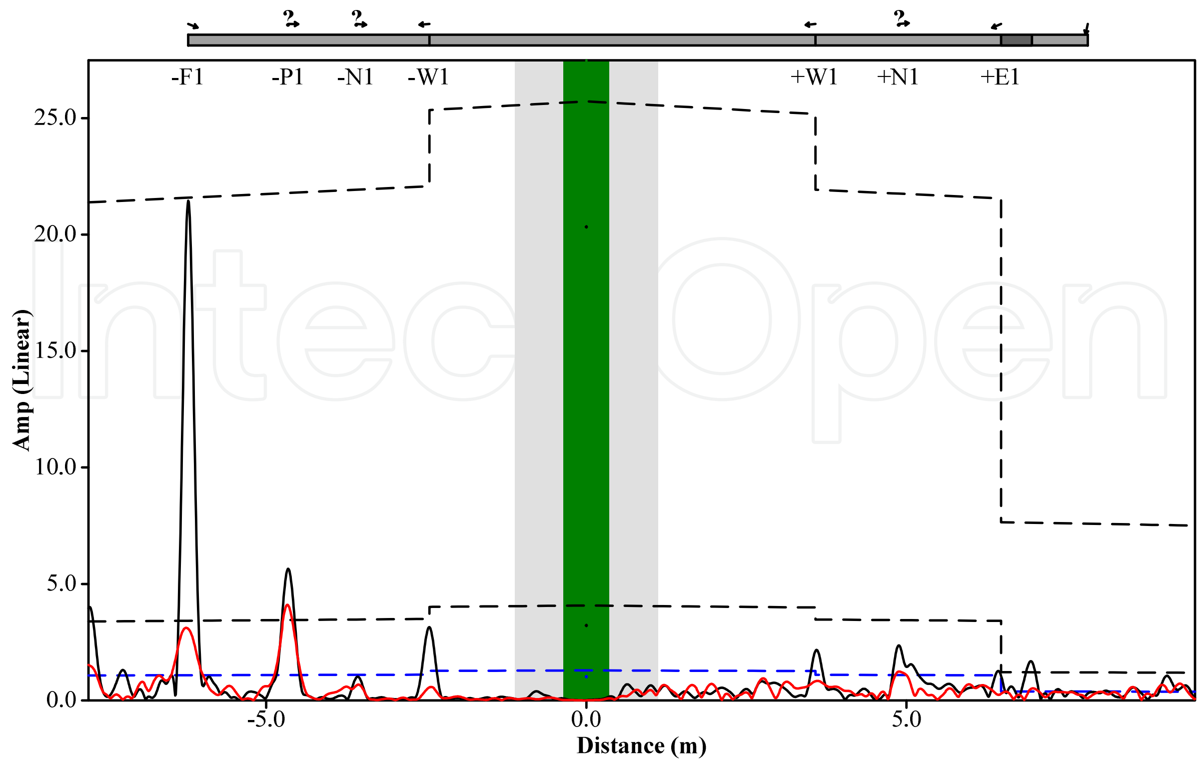


Fig. 3. Profile of the test pipe and the measuring system.

A commercial instrument is used to generate a 10 cycles Hanning-winded tone burst signal to excite the transducers. The frequency regime of guided wave is excited from -1.2 increased equally 0.2 of frequency band to 3.4 to propagate the torsional T(0,1) mode on the pipe for the measurement, respectively. When the transducer ring generates the T(0,1) mode



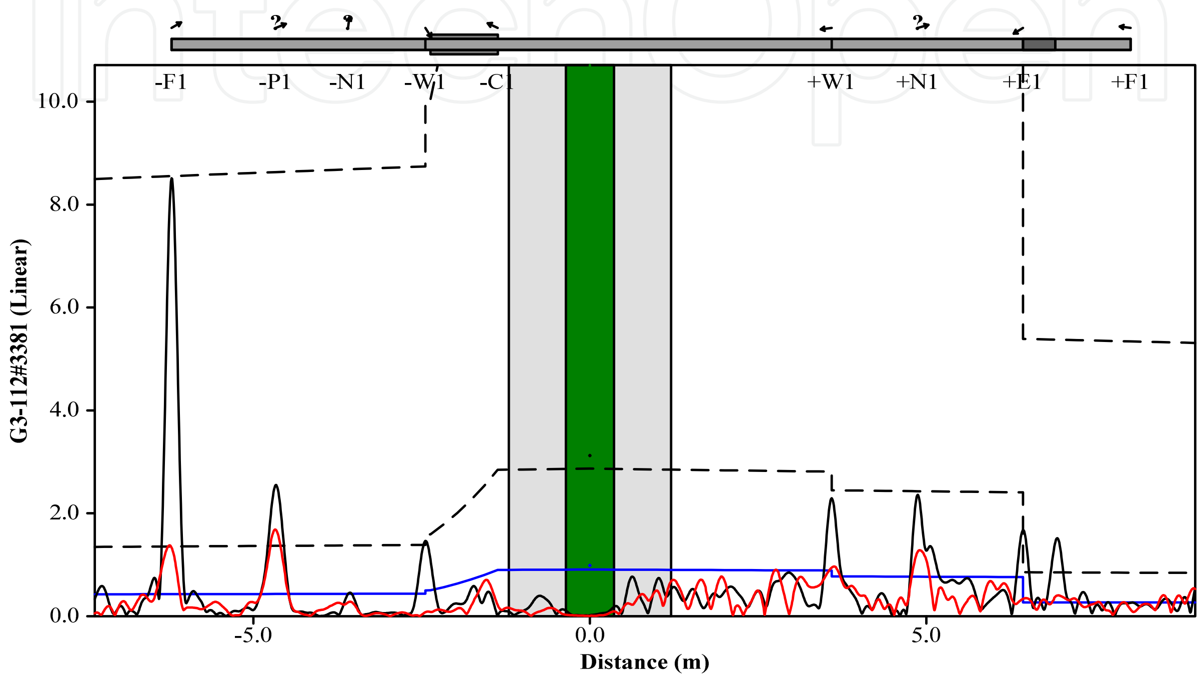
bare pipe

Fig. 4. The reflected signals of the test pipe at frequency regime 1.0 (unwrapped).

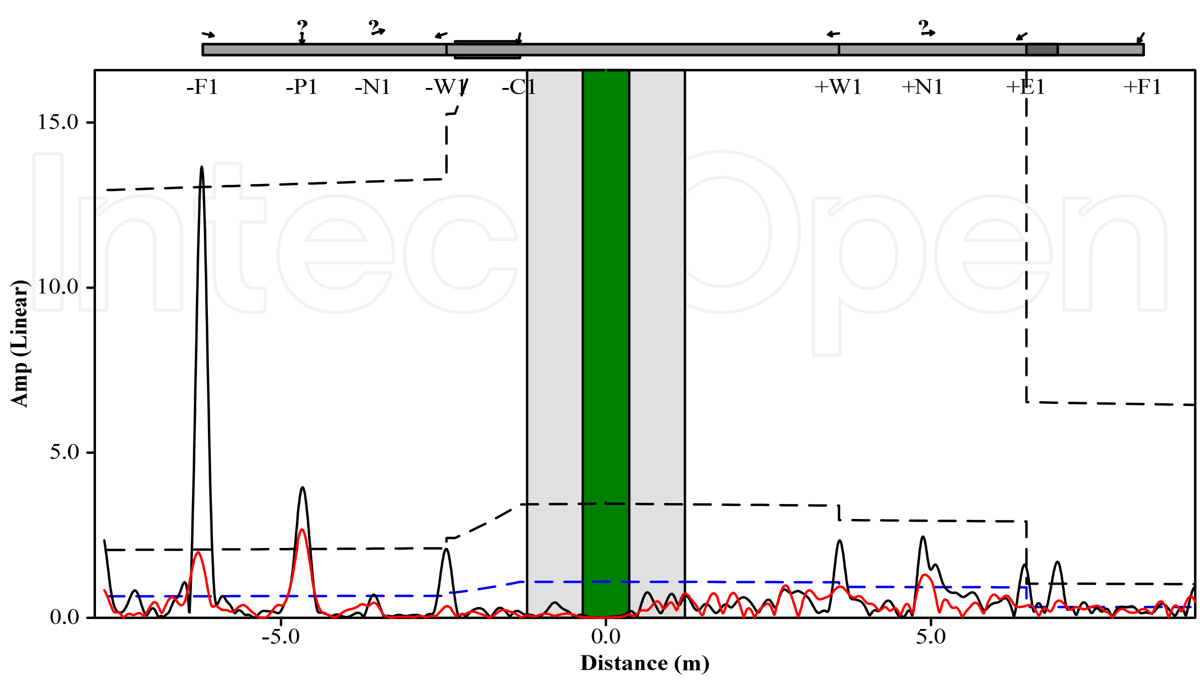
on the pipe, the guided wave can be propagated to both ends of pipe. The coated material is embedded on the pipe between the position of transducer ring mounted and flange for the experiments. Various coated materials which are used commonly in industrial plants, such as mineral wool (1-m length, 5-cm thickness, no adhesive material). Polyethylene (1-m length, 1-cm thickness, adhesive strength: 1.56 kg/25 mm), and bitumen (1-m length, 2-cm thickness, adhesive strength: 2 kg/25 mm), are used in experiments to measure the reflected signal for attenuation investigation (see Fig.5). In Fig.5, the amplitude of the reflected signal could be measured at the same position for the attenuation evaluation. At the flange feature –F1 for bitumen coating shown in Fig.5(a), the amplitude of reflection is 8.51 mV at incident frequency regime 1.0, the value is 13.6 mV for polyethylene coating shown in Fig.5(b), and the measured amplitude is 22.6 mV for mineral wood coating shown in Fig.5(c). Comparison of the amplitude value of the flange feature among Fig.5(a), 5(b) and 5(c) shows that the attenuation is significantly high for bitumen coating. In order to evaluate the effect of the coated materials for guided wave T(0,1) mode, the attenuation of reflected signal is measured by comparing the amplitude of the guided wave when the waveguide is in air to the amplitude as the waveguide is embedded by coated material over a given length, L, on the pipe. As mentioned before, measuring the reflected amplitude of the weld feature before and after embedding is measured as the reference reflector. The guided wave attenuation α_e over the embedded length L in the experiment is then calculated as

$$\alpha_e = \frac{1}{2L} 20\log[\frac{AF_a / Aw_a}{AF_b / Aw_b}] \qquad [dB/m] \tag{6}$$

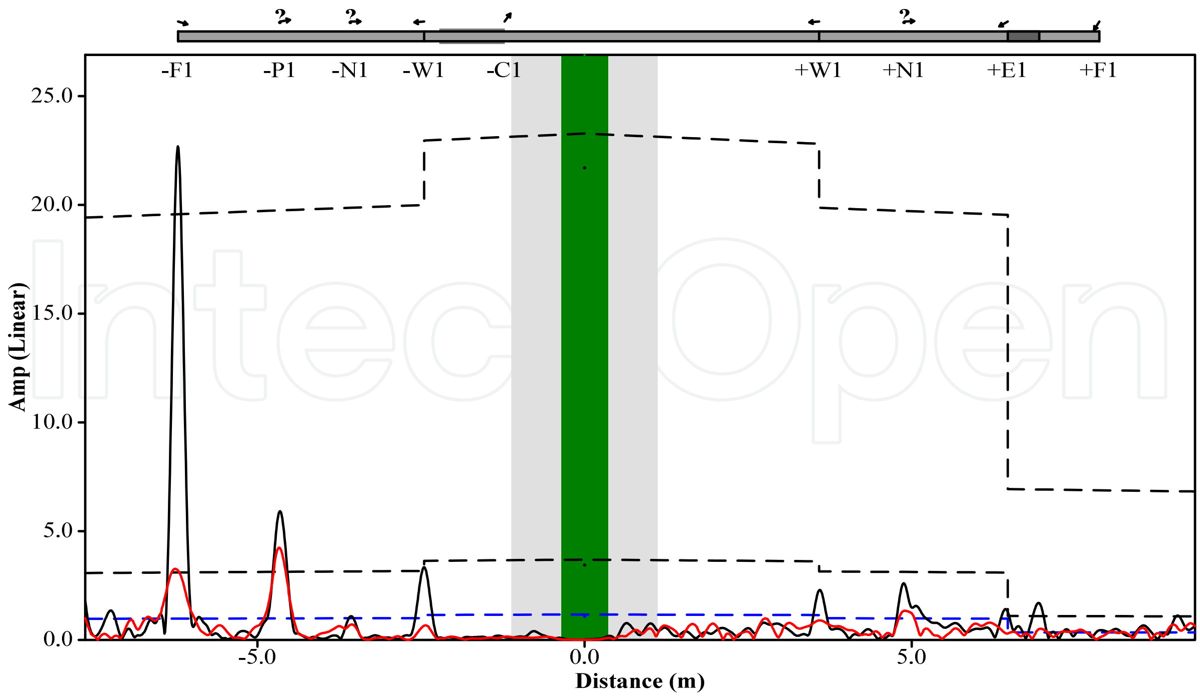
Here L is 1-m since the embedded length of coated material is united in the experiments. At a given frequency regime, the amplitude of the Fourier transforms of the flange reflection and the weld reflection before embedding are denoted by AF_b and Aw_b, respectively, and after embedding by AF_a and Aw_a, respectively. This attenuation α_e corresponds to Equation (5) of α for the excited frequency propagating in the pipe.



(a) bitumen



(b) polyethylene



(c) mineral wool

Fig. 5. The reflected signals of the experimental measurement; (a) bitumen, (b) polyethylene, and (c) mineral wool.

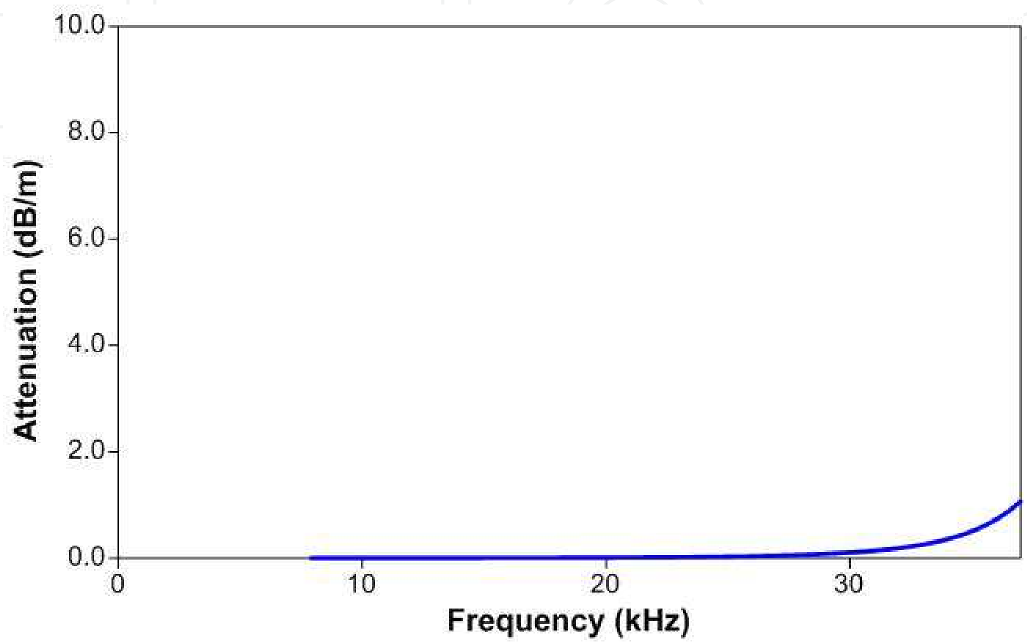
4. Results and discussion

4.1 Predictions

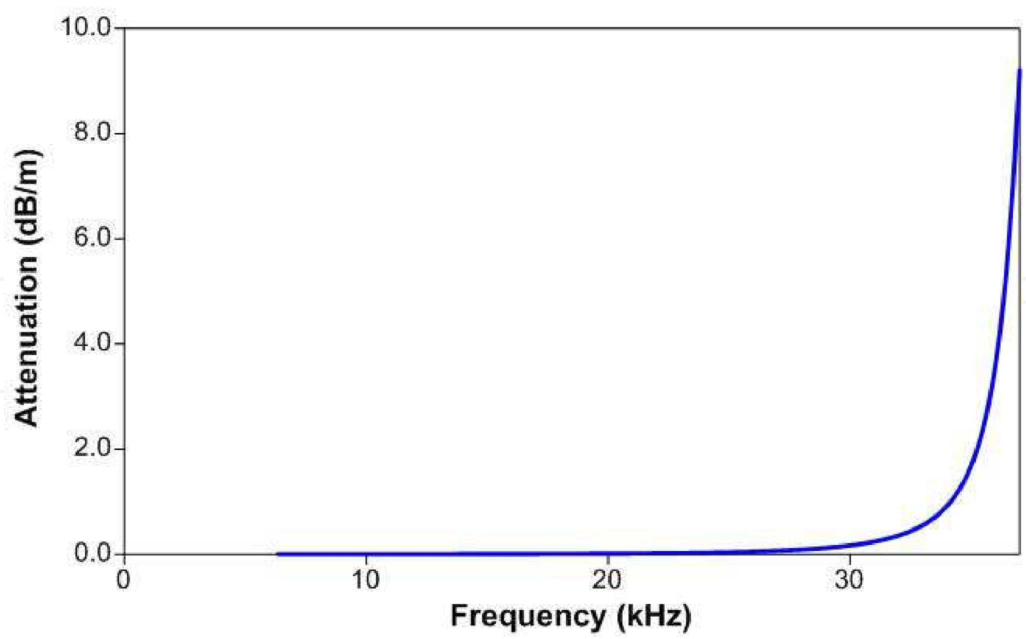
All the predictions presented in this paper were produced using the DISPERSE software. The software is based on the global matrix method for the analysis of multi-layered structures that over-comes the problem of instability at high frequency-thickness products commonly associated with the Thomson-Haskell transfer function technique [21]. When predicting the attenuation due to the material damping of the coated material, the DISPERSE software is used in this research. The acoustic properties of various coated materials are shown in Table 1. The attenuation of the prediction discussed for various coated materials are shown in Fig.6. Notice that the attenuation of guided wave for mineral wool is nearly zero at the frequency range of 10 to 40 kHz (there is no attenuation diagram can be shown in DISPERSE software), since the coated material of mineral wool has no adhesives strength on the pipe. It means that there is zero traction at the surface of the pipe, and the energy of guided wave has no leakage to the coated material. It is obviously that the attenuation of guided wave for polyethylene (Fig.6a) and bitumen (Fig.6b) of coated material have significantly decayed with frequency. This attenuation results due to the energy dissipation of guided wave by the viscous of viscoelastic material. The behavior of the viscoelastic material combines the energy-storing feature of elastic media, the dissipating feature of viscous layer, and frequency dependent in elastic moduli [22]. The traveling distance of guided wave T(0,1) mode in the pipe will be reduced by the higher attenuation. In Fig.6, the circumferential displacement through the pipe wall is dominant by the T(0,1) mode. The amplitude of displacement is reduced apparently for the cases of

Material	Density (Kg/m^3)	Shear Velocity (m/ms)	Shear attenuation (dB/m)	Thickness (mm)
bitumen	970	0.46	1516	6
polyethylene	950	0.95	1371	6
mineral wool	2500	2.0	0	10

Table 1. The acoustic properties of various coating materials.



(a) polyethylene



(b) bitumen

Fig. 6. Prediction of attenuation of guided wave for (a) polyethylene and (b) bitumen. The attenuation of guided wave of mineral wool cannot be shown in the DISPERSE software since the attenuation of guided wave is zero.

bitumen and polyethylene coated, while the material damping of them is heavier than mineral wool is. Another interesting result in Fig.6 is the higher frequency, the heavier attenuation of the guided wave. The reason is the high frequency has small wavelength, and can be easily dissipated the energy of guided wave into the viscous layer.

4.2 Experimental results

The experimental data is obtained using the experimental set-up shown in Fig.3. The amplitude of the reflected signals for the weld reflector and flange feature is measured to calculate the attenuation of guided wave before and after embedding the coated materials. Since the viscoelastic materials are very sensitive to temperature changes [22]. The measurements use the same set-up for various coated materials measurements and control the same temperature 28°C during the experiments in this paper. The results of measurements are shown in Table 2 for various insulation materials at selective frequency regime (0.2 to 3.0). The attenuation of guided wave is also shown in Table 2 which is calculated using Equation (6). It is found, as expected, that the attenuation of guided wave in the mineral wool coated material is near zero. This is because of the adhesive strength for mineral wool coated has no viscosity. Therefore, neither the amplitude of reflected signal nor the attenuation could be changed before and after embedding the coated material in the experimental measurements. Other interesting results are the cases of bitumen and polyethylene coated, since they have large adhesive strength. The amplitude value of the attenuation for guided wave is from 4.046 to 4.668 dB/m for bitumen coated, and the value range is from 2.235 to 2.453 dB/m for polyethylene coated at selective frequency regime (0.2 to 3.0). It became evident that the attenuation of guided wave is due to the leakage of energy into the viscous layer. On the other hand, the adhesive strength of bitumen coating and polyethylene coating is large enough that the T(0,1) wave leaks the energy into the viscous layer. The results of the experiment for various coated materials at selective frequency range are shown in Fig.7. Comparison of the results in Fig.7 with the results of predictions in Fig.6 shows that the attenuation of guided wave is significantly high for bitumen coating, slightly high for polyethylene coating, and there is almost no effect for mineral wool coating. The phenomenon of the predicted curves is clearly in agreement with the experiments for all case of various insulation materials on the pipe. Hence the agreement between the predictions and experiments for the attenuation of guided wave is excellent. In addition, the behavior of the higher attenuation of guided wave in the higher frequency has been observed. The reason for this variation with frequency is the small wavelength at high frequency cannot carry incident energy largely and easy to leak the energy into surrounding media.

For the traveling distance evaluation, the average attenuation of guided wave is used to calculate the propagating range for pipe inspection at selective frequency regime (0.2 to 3.0). The signal to noise ratio used in this experiment is 32 dB for the measuring instrument. It means that the noise or baseline level is set to 32 dB below the flange level, the 100% reflector, of the reflected signal. The traveling distance on pipe for the bitumen coating is about 7.53-m since the decay rate of guided wave is 4.250 dB/ m, take frequency regime 1.0 for example. For the polyethylene coating, the traveling distance is near 14.03-m for the decay rate of guided wave at frequency regime 1.0 is 2.281 dB/m. There is no effect on the traveling distance for the mineral wool coating. Hence, the amplitude of guided wave decreases exponentially with distance for T(0,1) mode propagating in the pipe. The value of

Coating: mineral wood															
Frequency regime	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
AW0	2.47	2.39	2.32	2.24	2.17	2.11	2.05	2.01	1.98	1.94	1.93	1.91	1.90	1.87	1.85
AF0	24.9	24.0	23.1	22.3	21.4	20.6	19.7	18.9	18.1	17.3	16.5	15.7	14.9	14.0	13.2
AW1	2.63	2.54	2.45	2.37	2.29	2.23	2.17	2.12	2.09	2.07	2.04	2.03	2.01	1.99	1.97
AF1	26.4	25.4	24.5	23.5	22.6	21.7	20.9	20.0	19.1	18.3	17.4	16.6	15.7	14.8	13.9
dB /m	-0.02686	-0.01062	-0.00765	-0.00321	0.00626	0.00050	-0.00055	-0.00099	-0.00203	-0.03558	-0.01132	-0.01583	-0.01904	-0.02155	-0.02371
Coating: polyethylene															
Frequency regime	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
AW0	2.47	2.39	2.32	2.24	2.17	2.11	2.05	2.01	1.98	1.94	1.93	1.91	1.90	1.87	1.85
AF0	24.9	24.0	23.1	22.3	21.4	20.6	19.7	18.9	18.1	17.3	16.5	15.7	14.9	14.0	13.2
AW1	2.67	2.58	2.50	2.41	2.33	2.27	2.21	2.17	2.14	2.12	2.10	2.08	2.07	2.05	2.02
AF1	16.1	15.5	14.8	14.2	13.6	13.0	12.5	11.9	11.4	10.8	10.3	9.81	9.29	8.75	8.20
dB/m	-2.23518	-2.24017	-2.2562	-2.27239	-2.28074	-2.30523	-2.32209	-2.33864	-2.35843	-2.40678	-2.39589	-2.41350	-2.42880	-2.44249	-2.45262
Coating: bitumen															
Frequency regime	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
AW0	2.47	2.39	2.32	2.24	2.17	2.11	2.05	2.01	1.98	1.94	1.93	1.91	1.90	1.87	1.85
AF0	24.9	24.0	23.1	22.3	21.4	20.6	19.7	18.9	18.1	17.3	16.5	15.7	14.9	14.0	13.2
AW1	2.65	2.55	2.46	2.37	2.29	2.22	2.16	2.11	2.07	2.05	2.03	2.01	2.00	1.98	1.96
AF1	10.5	9.99	9.46	8.98	8.51	8.06	7.63	7.23	6.85	6.48	6.13	5.78	5.44	5.11	4.77
dB/m	-4.04576	-4.09656	-4.15152	-4.19787	-4.24978	-4.29583	-4.34772	-4.39731	-4.43647	-4.50485	-4.52255	-4.56658	-4.60539	-4.63903	-4.66763

Table 2. The measurement results for various coating materials.

attenuation of guided wave for each frequency regime shown in Table 2 can also be calculated. Take bitumen coating at incident frequency regime 2.2 for example, the attenuation is 4.523 dB/m listed in Table 2. Therefore, the traveling distance of guided wave is 7.07-m for incident frequency regime 2.2 propagating on the pipe of the bitumen coating when the T(0,1) mode is excited by 10 cycles Hanning-windowed tone burst signal.

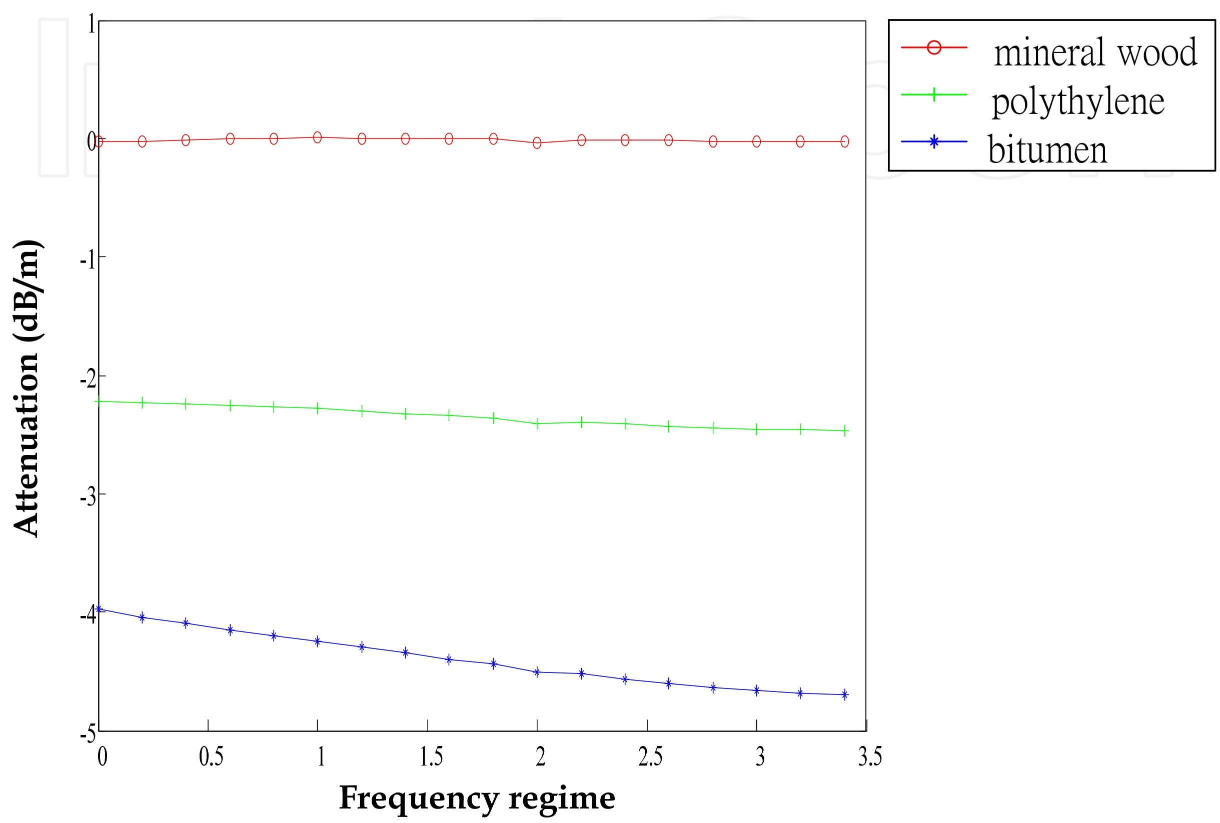


Fig. 7. The results of the experiment for various insulation materials.

5. Conclusions

Good agreement has obtained between the experiments and predictions for the attenuation of guided wave study on the insulation pipe. The effect of the adhesive strength on the pipe is investigated for various coated materials. The results show that the bitumen coating on the pipe has 4.046 to 4.668 dB/m attenuation of guided wave, the polyethylene coating has 2.235 to 2.453 dB/m, since the adhesive strength of the bitumen coating is larger than the polyethylene coating is. There is no effect on the torsional T(0,1) mode for mineral wool coating because it has no adhesive strength applied on the pipe. In addition, the traveling distance of the torsional T(0,1) mode on the pipe is evaluated in this paper. It can travel about 7.53-m for bitumen coating, and the traveling distance is near 14-m for polyethylene coating, while the guided wave is excited to propagate the pipe for pipeline inspection. For mineral wool coating, the propagating range depends only on distance due to the natural decay of material properties of the pipe. The results of this study are of interest refinery, chemical and petro-chemical industrial plants for pipeline inspection, since a high proportion of these industrials pipelines are wrapped with the coated material for the necessary of their work.

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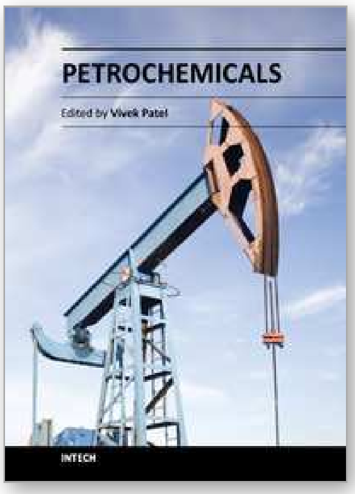

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