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Non-Destructive Evaluation of Multi-layer Piping using Laser Ultrasonic Technique

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Abstract
Recently, multilayer piping has been used widely. Multilayer piping has excellent durability and corrosion resistance. An effective means for quality maintenance of multilayer piping is the laser ultrasonic technique for checking the state of adhesion of the vinyl chloride layer and the steel layer of multilayer piping. The wave is refracted at the interface between the steel layer and the vinyl chloride layer based on the wave motion principle. The arrival time of the reflection wave was calculated and confirmed by measurements. If measurement of piping under high temperature becomes possible, the effectiveness of the non-destructive testing technology by the laser ultrasonic technique can be expected, enabling the production of higher reliability and quality of multilayer piping.
Keywords: Laser ultrasonics, surface fatigue crack , adhesion, multilayer piping, crack, corrosion

1. Introduction

Recently, environmental problems of the piping used for water service have become a serious concern. Multilayer piping has excellent durability and corrosion resistance. Therefore, multilayer piping has been promoted widely. The main piping in the water service tube is a steel pipe with a lining of plastic [1]. Fig. 1 shows the structure of a multi-layer piping. In this vinyl-lined steel pipe, one of the important quality element in the manufacturing process is the press-fit into the steel layer of the multilayer piping. Non-destructive testing that uses the ultrasonic waves are suitable to evaluate the adhesion state of multilayer piping. Laser ultrasonic wave is effective as the means to do this without contact. When there is an air gap, it does not spread at all, or the signal attenuates extremity. And it will be excited by the laser light of the high energy density irradiated on the surface of the steel pipe. At the detection point that is a long distance from the excitation point, experimental investigation is performed to detect the spreading of surface wave or the longitudinal wave and transverse wave.

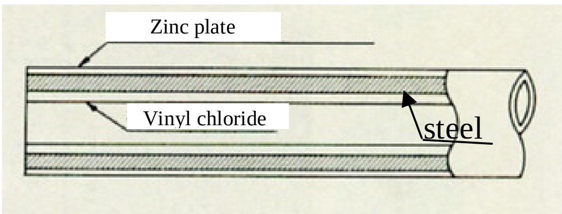


Figure 1. Structure of multi-layer piping.

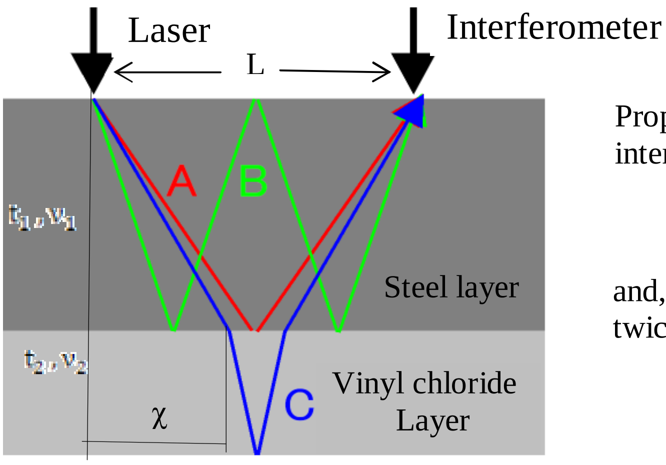
Most of the energy is concentrated a few wavelengths under the surface of piping [2]. In addition, the spreading time of the ultrasonic signal should be influenced by the material and thickness, and a correction coefficient should be used for the curved surface of the tube in the direction of the circumference. It is necessary to adjust the angle of incidence, and to confirm whether the wave is a longitudinal wave or a surface wave, in the case of inspection where the tube diameter is small. It should be possible to perform

inspection using laser ultrasonic waves when the examination body is moving and at high temperature [3]. It is known that the speed of the surface wave is about 1/2 the longitudinal wave speed, and is slightly smaller than the transverse wave speed [2].
In this study, we focus on the longitudinal wave, which is reflected by the structure in the multilayer piping. The laser ultrasonic wave was emitted and detected on the surface of the steel and this was done in the vertical direction without contact. An experimental examination and a verification test were performed to clarify the state of adhesion in the multi-layer piping by the reflection and refraction of the longitudinal wave.

2. Theory

2.1 Geometrical analysis

The arrival of the C wave (back reflection) that is shown reflected from the longitudinal wave (A: reflection of the first wave, and B: multiple reflection wave), is shown in Fig. 2. The back reflection C wave of the vinyl chloride was calculated by considering the refraction of the wave at the interface.



A= reflection of the secondary wave
B= reflection of the first wave
C= back reflection wave

Figure 2. Paths of reflection waves

Propagation time of wave A reflected at the interface is given by

$$T_A = \frac{2}{v_1}\sqrt{t_1^2 + \left(\frac{L}{2}\right)^2}$$

and, the time of wave B, which is reflected twice is given by

$$T_B = \frac{4}{v_1}\sqrt{t_1^2 + \left(\frac{L}{4}\right)^2}$$

The propagation time of the refracted wave C is given by

$$T_C = \frac{2}{v_1}\sqrt{t_1^2 + x^2} + \frac{2}{v_2}\sqrt{t_2^2 + \left(\frac{L}{2} - x\right)^2}$$

x is the distance from the irradiation point to the refraction point. t_1 is the thickness of the steel layer, and t_2 is the thickness of the vinyl layer. v_1 and v_2 are the respective sound speeds. These are shown in Table 1.

Table 1. Velocity and thickness for the tested tube

No.	Item : Velocity and distance	Parameter
1	The steel sound speed of the longitudinal wave	v_1=5950 m/s [6]
2	Material layer thickness in the steel	t_1=2.6 mm
3	The longitudinal wave speed of the vinyl chloride.	v_2=2390 m/s [7]
4	Vinyl chloride layer thickness	t_2=1.5 mm

The thickness of the steel layer and the vinyl chloride layer depends on the standard of the multilayer pipe (cf. JISG3442 or JISG3452 [5], etc.) and is shown in Table 2 and Fig. 3. The speed of sound in the vinyl chloride was assumed to be equal to the speed of sound in poristirorl (2340 m/s) [6].

Table 2. Dimension of steel pipe (in mm)

Name (A)	Lining pipe			Steel pipe	Vinyl tube
	Outside Diameter D_1	Thickness t_1	Inside Diameter d	Thickness t_2	Thickness t_3
15	*21.7*		*13.1*		
20	*27.2*	*4.3*	*18.6*	*2.8*	*>1.5*
25	*34.0*	*4.7*	*24.2*	*3.2*	

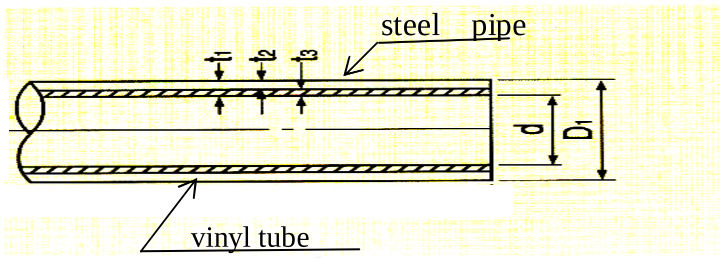


Figure 3. Dimensions of the multilayer pipe sample.

2.2 Calculation results

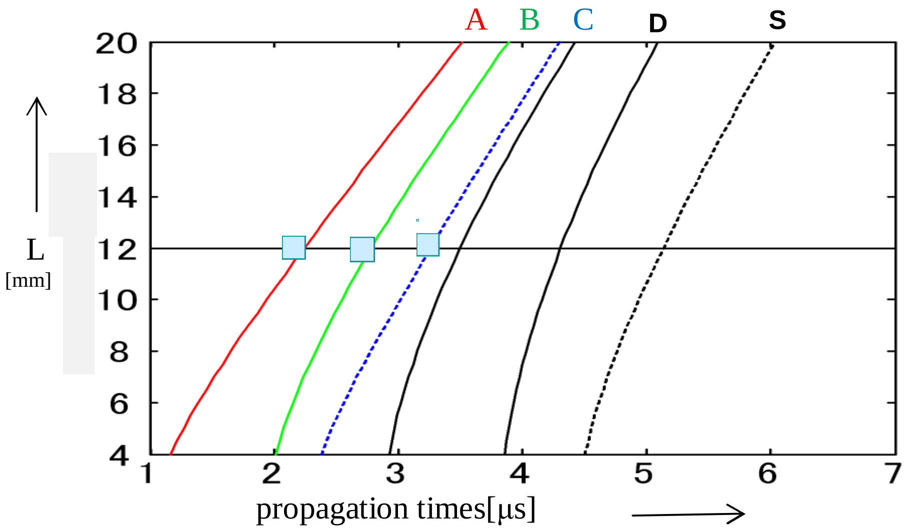


Figure 4. Calculated propagation times.

The arrival times of the A, B, C waves were calculated as a function of L, the distance between the laser irradiation point and the interferometer point. The results are shown in Fig. 4.

3. Experimental procedure

3.1 Experimental setup

The experimental setup used to detect the state of adhesion of the vinyl chloride layer and the steel layer of the multilayer piping is shown in Fig. 5. The laser light (1) is focused by a mirror (2a) and a lens (3c). A supersonic wave is excited on the surface of the steel pipe (4a) and spreads to the vinyl chloride layer (4b) inside the steel pipe. The reflected wave from the interface and the inner surface is detected by an interferometer to a lens (3d) and a mirror (2b). Information on each wave is detected and recorded by a wave drawing set (7) and operating set (8). The interferometer uses a Nd:YAG laser with wavelength, 1064 nm, peak power of 500 W, and laser spot diameter of 2 mm. The bandwidth is limited to 800 kHz - 10 MHz.

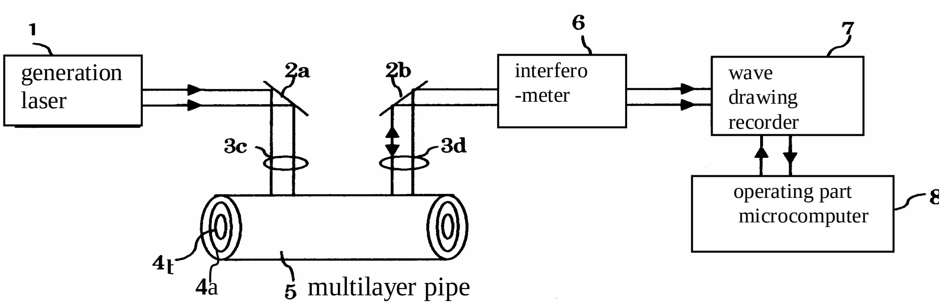


Figure 5. Experimental setup.

Taking the refraction of the wave at the interface of the vinyl chloride into consideration, the arrival times of the reflection wave from the interface were calculated to be 2.25 μs and 2.78 μs, and the arrival time of the reflection wave from the back of the vinyl chloride was found to be 3.26 μs. This agrees well with the experiment results shown in Fig. 6 and the calculation result of Fig. 4.

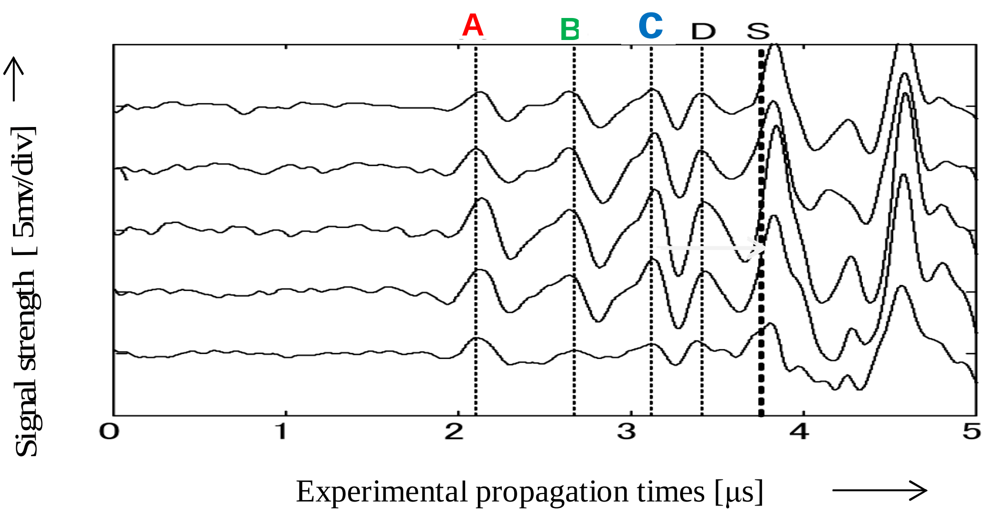


Figure 6. Measured ultrasonic waveform.

3.2 Experimental results

The calculation results for the arrival time to the isolation distance 9 mm were clarified for the coated piping composed of two layers, on the boundary side of the medium with different speeds of sound, or considering the refraction of the wave of the interface of the steel piping. The sound speed, the angle of incidence of the adjoined medium, and the reflection angle are assumed to be related according to $\sin\theta_1/v_1 = \sin\theta_2/v_2$ (θ is incidence angle of the wave relative to the normal and v are the sound wave velocities, in steel (v_1=5950 m/s), and vinyl chlorides (v_2=2390 m/s) by Snell's law [4]. This law obeys the wave motion principle assuming that the material is continuous, normal to the interface displacement. In conclusion, it has been understood that an excellent reflection waveform is gotten when the separation is about 9mm ～12 mm.

3.3 Verification using artificially degrading specimen

As shown in Fig.7, the part was made of two layers, and a part of the vinyl chloride layer in the multilayer piping was peeled off. The laser beam was irradiated from outside of the multilayer piping. The sample was scanned in 2 mm steps so that the back reflection point extended beyond the boundary of the part without the vinyl chloride layer and the normal part of two layers. At a separation distance of 9 mm, the reception signal was observed with the interferometer. Fig.8 shows the calculated results. Fig. 9 shows the measurement results.

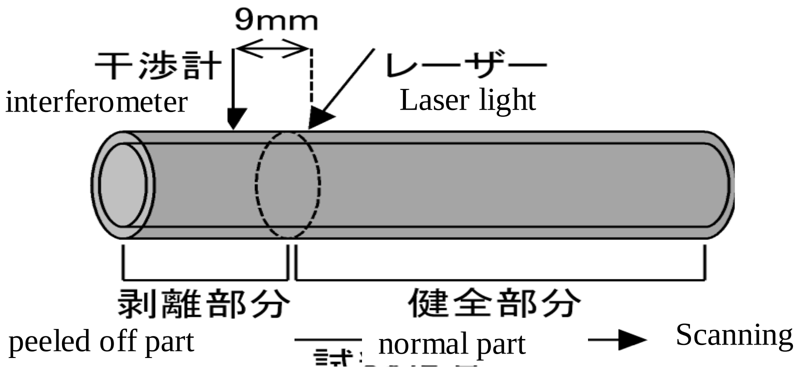


Figure 7. Piping exmination sample

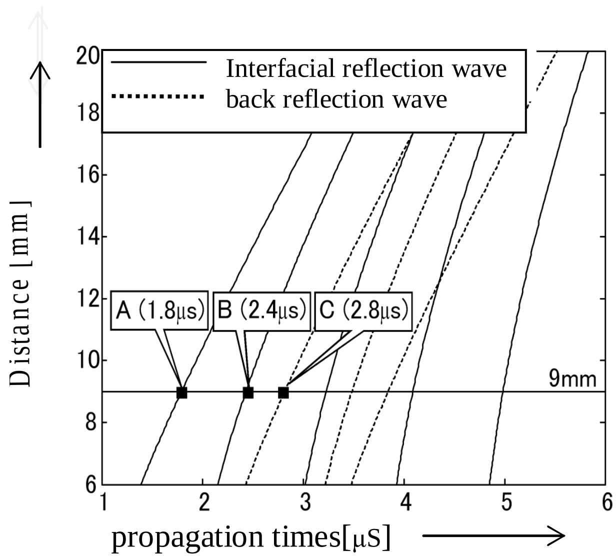


Figure 8. Calculated propagation times

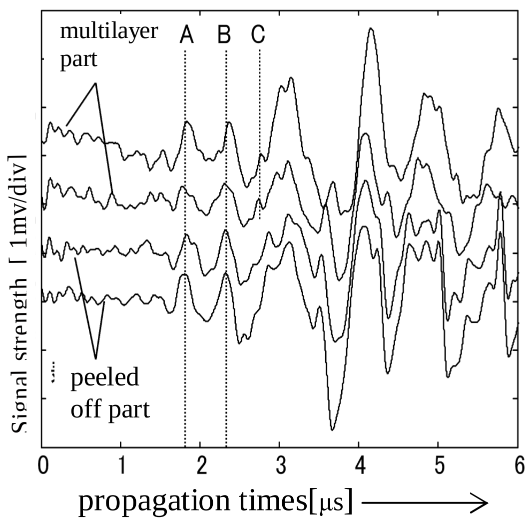


Figure 9. Measured ultrasonic waveform

The configuration of the waves could be confirmed for waveforms A and B of the reflection from the multilayer part (of normal part) and the part without vinyl chloride. The arrival time of the reflection wave corresponded to the calculation result extremely well as shown in Figure 8. The signal strength was 1 mV/div as shown in Figure 9, and the back reflection wave C in the vinyl chloride layer could be confirmed, the back reflection wave C in the multilayer part was also confirmed though the output wave signal was small.

However, in the part without vinyl chloride the signal does not appear at the same time. This implies that the ultrasonic wave does not spread when there is a small gap. This means that the level of the adhesion of the vinyl chloride tube and the steel pipe becomes a quality process element as the tube material production. The adhesion between the two layers was found excellent from this experiment verification.

4. Conclusions

The problem of adhesion of a multilayer piping, a one step method was developed concerning that was without contact by using laser ultrasonic technique. Steel tubes for piping for extinguishing fires are provided to test non-destructive of hydraulic pressure test, ultrasonic test and ECT (technique of the eddy-current). They have excellent corrosion resistance and high reliability, which is required for the given environment. If laser measurements in extreme and high temperature environments becomes possible, the effectiveness of non-destructive testing can be expected to be improved further.

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References

1. K.Yamazaki, corrosion of plumbing pipings and its countermeasures, *Journal of JSNDI*, 45, pp. 128-135, 1964.
2. Y.Kikuchi, *Ultrasonics Detection Method,* edited by Nihongakujutusinkoukai Press, pp. 187-188, JAPAN, 1964.
3. T.Fukuchi and T.Ogata,'Laser ultrasonic technique method with photorefractive interferometer', *Ultrasonics Technol.*, 17, pp. 30-35, 2005.
4. C.B. Scruby and L.E. Drain, *Laser Ultrasonics, Adam Hilger,* pp. 259-260, NY, 1990.
5. JIS G3452, *Carbon Steel Pipes for Ordinary Piping,*pp. 3, JAPAN, 2004.
6. M.Kanzan, *Chronological scientific tables*, edited by National astronomical observatory, published by Maruzen Co.,Ltd. pp. 422-423, JAPAN,2008.
7. Y.Kikuchi, *Ultrasonics Detection Method,* edited by Nihongakujutusinkoukai Press, p. 634, JAPAN, 1964.