A Study on Fatigue Characteristics of API 5L X42 Gas Pipeline

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Abstract: Generally, gas pipelines are buried in depth of less than 1.5 m from the ground or are exposed on the ground to handle the process of gas. Therefore, gas pipelines are repeatedly damaged by various types of external loads. Especially, because earthquake-induced damage to the gas pipelines can lead to fire by a gas leak and damages of human lives and properties, the integrity of gas pipelines is highly significant. For these reasons, an earthquake resistant design must be applied to gas pipelines considering the importance and characteristics of structures. For this, the evaluations of mechanical properties of gas pipelines for seismic loads should be performed. Therefore, in this study, API 5L X42 gas pipelines were used for estimation of fatigue behavior of gas pipe line structures. The ASTM standard specimens and curved plate specimens were collected from an API 5L X42 gas pipeline, and the fatigue tests were performed. Also, after the Stress-Number of cycles curve was obtained, we compared and examined them.

1. Introduction

Millions of pipelines to supply natural gas have been established in the world. Buried under the road, the pipelines to supply natural gas are exposed to the fatigue loads from vehicles, soil, cold and inner pressure which the season and date varies the natural gas transportation.(1) If the gas pipeline has been damaged by natural disasters such as earthquakes that occur frequently, as well as the leakage of pressure, the secondary disaster like the risks of fire and explosion will exist.

Therefore, many studies have been performed to evaluate the lifetime of the gas pipe to the need for further evaluation of the life and the current status of the gas pipe.

The natural gas pipe used in this study was small in diameter. It was exposed on the ground and used mainly in the metering system of the gas supply station for the gas flow stabilization of the inner gas transportation.

As shown in Figure 1 and Figure 2, the gas pipe will be heavily influenced by external loads such as seismic loads according to the shape and method of fixed condition.

Therefore, in order to find out the fatigue fracture characteristics of the API 5L X42 gas pipes used in the metering line, we performed destructive fatigue tests and determined its fatigue characteristics.

For this, the standard specimen was prepared according to ASTM(American Society for Testing Materials) E8 and E466. And the fatigue test was performed according to E8 and E466.

For the evaluation of the fatigue life of the pipe, having the same surface condition of the actual pipe, we performed fatigue tests and investigated the fatigue characteristics in accordance with the shape of the curved plate specimens.

Fig. 1 The metering facilities of a gas station

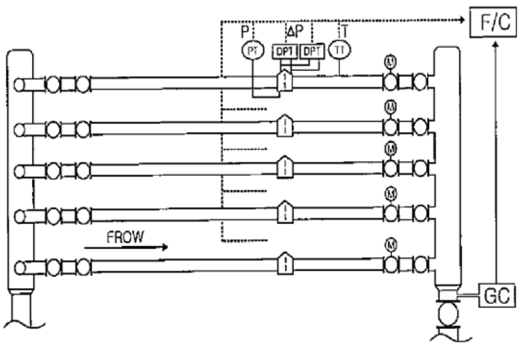


Fig. 2 The schematic diagram of gas station metering facilities

2. Specimens and test procedures

The tensile test was performed to obtain the Stress-Strain diagram of API 5L X42 pipe. In accordance with ASTM E8, the tensile specimens were collected from API 5L X42 pipe for this purpose, the shape of the tensile specimens are shown in Fig. 3.

The fatigue testing was performed to obtain the Stress-Number of cycles diagram of API 5L X42 pipe. For this, the fatigue specimens were taken from API 5L X42 pipe in accordance with ASTM E466 as shown in Fig.4.

Shown in Fig.5, the tensile tests and the fatigue tests were performed using INSTRON hydraulic testing machine (Model 8802) and hydraulic grips.

The tensile tests were carried out at a rate of 2 mm/min and the deformations of specimens were measured using the INSTRON G.L.25 Extensometer.

And the Stress-Number of cycles diagram can be varied with ratio of the maximum load of the minimum load. So, the loading conditions of fatigue tests of the standard specimen were performed on the loading ratio R = 0.1 and R = -1 conditions because of the possibility of strain hardening. In condition of the loading ratio R = 0.1, the fatigue tests were performed at 7 Hz of sine wave. And in condition of the loading ratio R = -1, the fatigue tests were performed at 2 Hz of sine wave. In order to reduce the notch effect of the fatigue test specimens, shown in Fig. 4, all surfaces of the reduced parts of specimens were polished. The seven standard specimens were prepared and the fatigue tests were performed with different loading conditions as shown in Table 1.

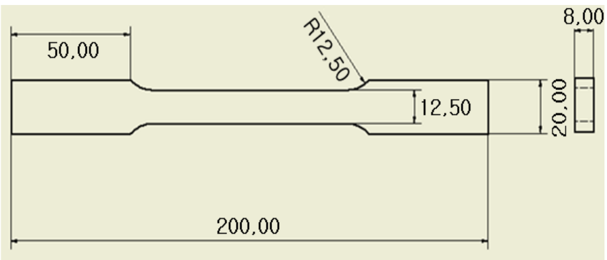


Fig. 3 Tensile test specimen

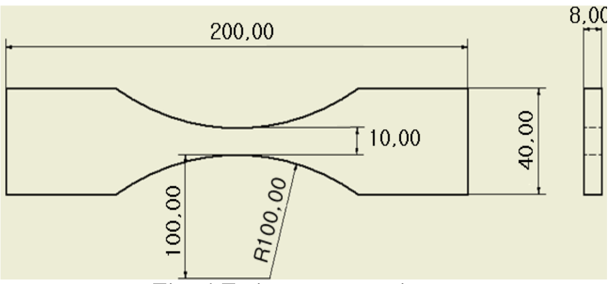


Fig. 4 Fatigue test specimen

Fig. 5 The hydraulic test machine and extensometer

Table 1 Condition of fatigue test (R=0.1)

API 5L X42 Gas Pipe (R=0.1)	
Specimen	Max. Stress (MPa)
FT1	350
FT2	380
FT3	420
FT4	440
FT5	450
FT6	455
FT7	460

For the evaluation of the fatigue life of the pipe having the same surface condition of the actual pipe, curved plate specimens were prepared as shown Fig.6 and the fatigue tests were performed 7 times at 2 Hz of sine wave in condition of the loading ratio R = -1 like the previous cases of the standard fatigue specimens.

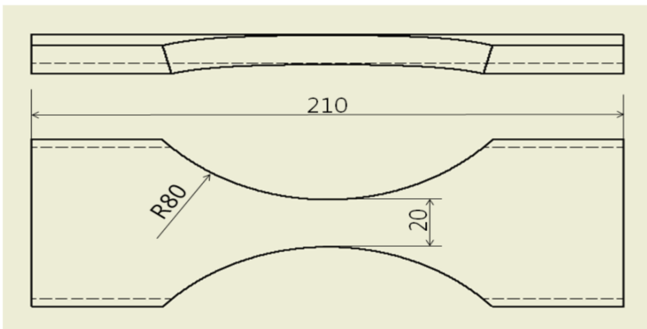
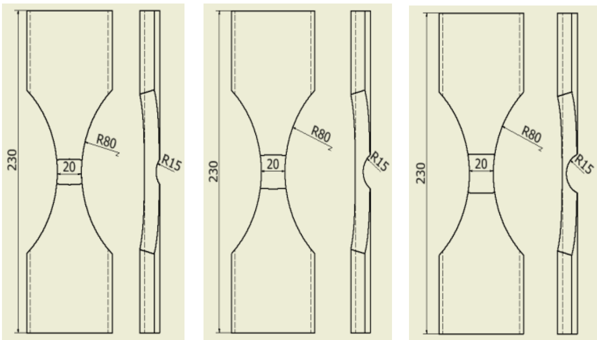


Fig. 6 Curved plate specimen

Fig. 7 Fatigue tests of curved plate specimens

In order to evaluate the influence of the depth-thinning, the depth-thinning of 25%, 50%, 75% were inserted to the width center of curved plate specimens and then the fatigue tests were performed.



(a) 25% (b) 50% (c) 75%

Fig. 8 Depth-thinned curved plate specimens

3. Test Results and Discussions

The tensile tests of standard specimens taken from the API 5L X42 gas pipe were performed three times and the results of this tensile tests were shown in the Fig. 9. The yield strength and tensile strength were determined using the average value of the three tests results. The yield strength was 395 MPa and the tensile strength was 465 MPa as shown in Table 2.

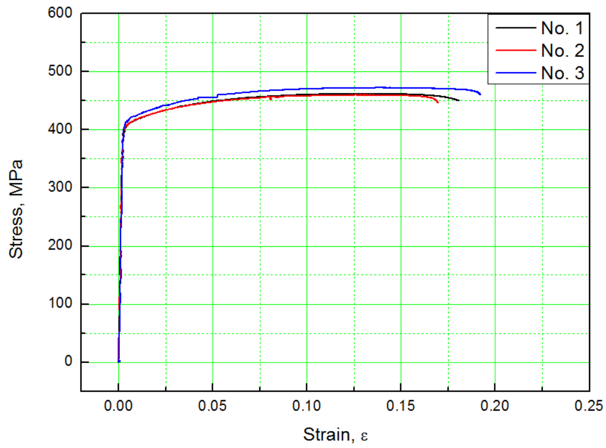


Fig. 9 Result of tensile tests(5)

Table 2 Results of tensile tests

API 5L X42 Gas Pipe	
Yield Strength	395MPa
Tensile Strength	465MPa

The fatigue tests were carried out 7 times according to the different experimental conditions of Table 1, the S-N data was obtained from these tests as shown in Fig. 10.

These fatigue tests of a loading condition R=0.1 were completed in case of 1,100,000 cycle and in this tests, the strain hardening phenomenon occurred due to the plastic deformation that appears in the soft material. Because of this phenomenon, we expected that the elastic limit(yield strength) increased and the infinite fatigue life was shown in the load condition of 465 MPa closer to the tensile strength.

Therefore, the fatigue tests were performed by applying a loading condition of R=-1 for continuous strain hardening of material. The results of these tests were shown in the Fig. 11 and the S-N Curve of standard specimens collected from API 5L X42 pipe was acquired and the life cycle equation of standard specimens can be expressed in equation (1).

$$S_a = 606.55N^{-0.063} \tag{1}$$

Where, S_a : Stress amplitude (MPa)

N : Number of cycle

Therefore, the fatigue tests of API 5L X42 pipe should performed in the condition of R=-1 for the evaluation of fatigue life.

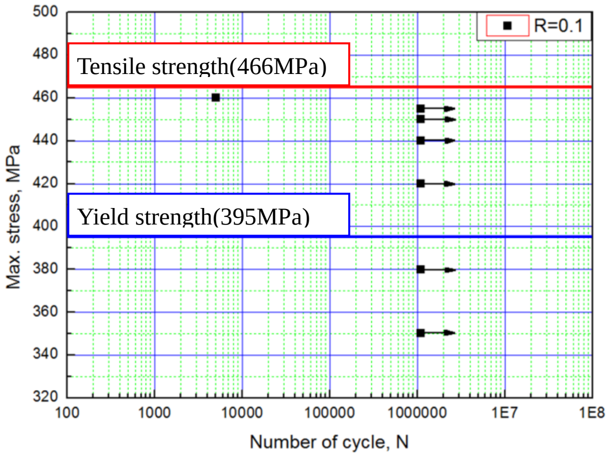


Fig. 10 S-N data of API 5L X42 gas pipe (R=0.1)

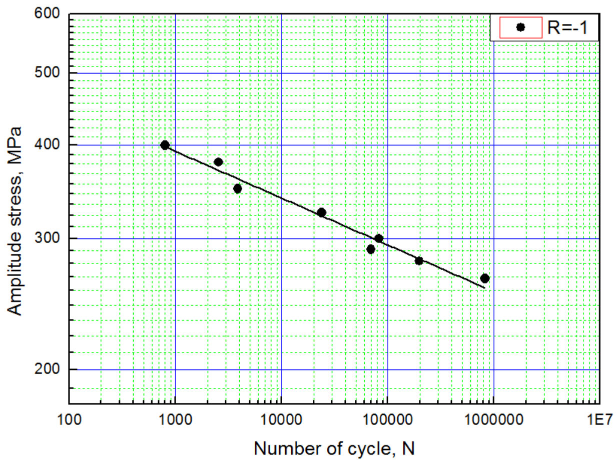


Fig. 11 S-N Curve of API 5L X42 gas pipe (R=-1)[5]

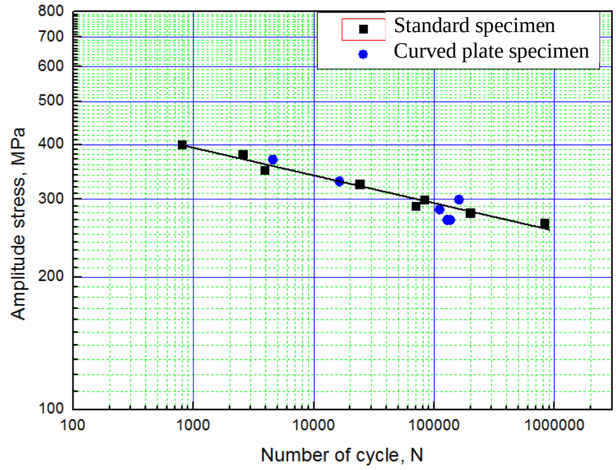


Fig. 12 S-N Curve of Standard and curved plate specimen(R=-1)

(a) Standard (b) curved plate

Fig. 13 Fracture shapes of specimens

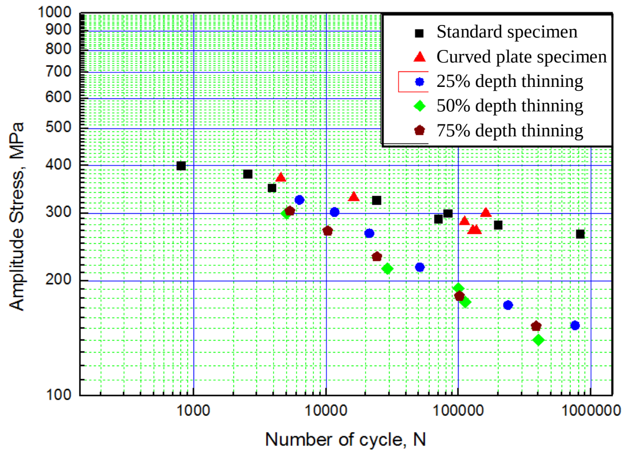


Fig. 14 Results of depth-thinned curved plates

Further fatigue tests were performed using the curved plate specimens in order to evaluate the same surface condition of actual pipe.

Compared to the standard specimens, the curved plate specimens' results were substantially similar to the standard specimens' results as shown Fig. 12. And as shown in Fig.13, the fracture shapes of specimens were similar. So, it was expected that there is no influence of the specimens shape in the fatigue tests of API 5L X42 gas pipe.

To evaluate of depth-thinning effect, the fatigue tests of depth-thinned curved plate specimens were performed.

The results of these fatigue tests as shown in Fig. 14, the slope of the S-N curve of the curved plate was larger according to their increasing depth-thinning. And it could be seen that there is no significant change in more than 25% depth-thinning. In addition, the results of more than 50% depth-thinning have almost similar effect of depth-thinning.

4. Conclusion

In order to find out the fatigue fracture characteristics of the API 5L X42 gas pipe used in the metering line, we performed several destructive fatigue tests and determined the fatigue characteristics.

For this, the standard specimens were prepared according to ASTM E8 and E466. And the Fatigue tests were performed according to E8 and E466.

For the evaluation of the fatigue life of the pipe which has the same surface condition of the actual pipe, we performed fatigue tests and investigated the fatigue characteristics in accordance with the shape of the curved plate specimens.

And we could get the followings.

1) The fatigue tests of a loading condition R=0.1 proved that the specimens of API 5L X42 gas pipe have infinite fatigue life. And in the fatigue tests of a loading condition R=-1, the life cycle equation of standard specimens was obtained using the S-N curve.

2) The slope of the S-N curve of the curved plate was larger according to their increasing depth-thinning. And it could be seen that there is no significant change in the over than 25% depth-thinning. In addition, the results of more than 50% depth-thinning have almost similar effect of depth-thinning.

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