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Failure analysis of a thermally insulated pipeline in a district heating system

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ABSTRACT

Failure analysis of a thermally insulated pipeline which failed during operation in a district heating system was performed by utilizing optical and electron microscopy in addition to various mechanical tests. The fractographic investigation showed that a crack initiated at the inside of the pipe and propagated to the outside. The crack was initiated at the toe region of the weldment and propagated along the transverse direction of the weldment. In the mechanical tests, the low toughness and hydrogen sensitivity of the weldment affected the failure of the thermally-insulated pipeline. In short, the interaction of the multiple effects in the HAZ, including the lower mechanical properties, stress concentration, and hydrogen susceptibility, led to pipe failure.

1. Introduction

District heating (DH) systems supply heat for occupants of large metropolis areas [1,2]. A DH system has various advantages, including increased energy efficiency and performance, as a result of implementing advanced equipment and maintaining the equipment in a professional manner; this decreases the cost and environmental impact [2,3]. A DH system is mainly composed of a heating plant distribution network of thermally-insulated pipelines and heat exchangers for end users. A typical DH system is illustrated schematically in Fig. 1.

Various failure cases can occur in each part of the DH system. In particular, failure of the network significantly influences the heat efficiency, cost, and safety because the heat distribution network (pipeline) is important in a DH system. There are various factors which affect the failure of thermally insulated pipes such as thermal fatigue or shock, poor welding, external impact, and corrosion. Thus, failure analysis is important to prevent the failure factors and for appropriate construction and maintenance of the thermally insulated pipeline.

In fact, the failures analysis and research about underground pipeline used in various fields such as petroleum, gas and water have been reported [4–14]. Corrosion and hydrogen damage are the main threat to the safety and durability of pipelines. In the case of external or internal corrosion, most studies are focused on the effect of the corrosive environment factors and various corrosion modes [15]. Also, the stress corrosion cracking (SCC) and the corrosion fatigue cracking (CFC) have been observed in the applied stress such as pressure, thermal fatigue and external damage with corrosion environment. Hydrogen embrittlement makes various types of metals brittle, decreases their mechanical properties and causes unexpected failure of the structure [4,13]. Thus, consideration of these two factors is important for the failure analysis of underground pipeline system.

However, these studies are almost focused on the petroleum and gas pipeline system. The sufficient attenuation of pipeline failure in the DH system (water transportation system) has not been given. Thus, in this study, a fractured thermally insulated pipeline after

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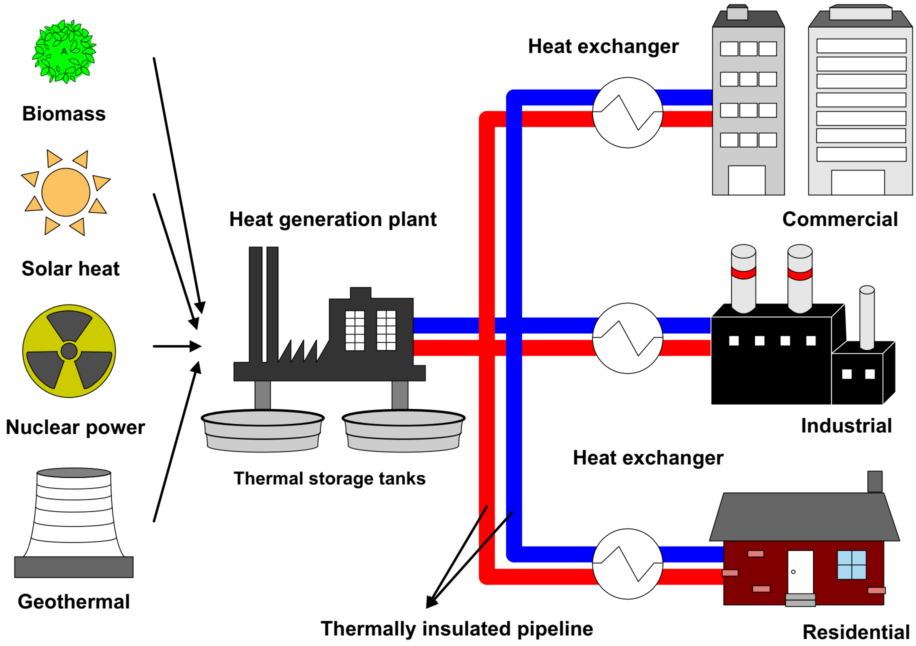

Fig. 1. Schematic diagram of the DH system.

Table 1
Chemical composition of district heating water (mg/L).

Cl^-	Mg^{2+}	Ca^{2+}	NH^{4+}	pH
14.6	0.48	1.06	1.53	10.0

Table 2
Chemical composition of the heat pipe used in the DH system in Korea (wt%).

Alloy code	Alloying elements			
	C	P	S	Fe
KS D3583 (ASTM A139)	0.25	0.008	0.005	Bal.

Table 3
Welding procedure specifications.

Welding process	GTAW$^{(A)}$ + SMAW$^{(B)}$
Joint design	Single-V joint with a 60-degree included angle and a 1.6-mm root face
Electrode	GTAW ER70S-G (6-mm diameter) SMAW E7016H (3.2-mm diameter)
Voltage	GTAW: 12 V to 15 V, SMAW: 20 V to 27 V
Current	GTAW: 100 A to 180 A SMAW: 140 A to 250 A
Polarity	GTAW: DCSP$^{(C)}$, SMAW: AC$^{(D)}$
Travel speed	GTAW: 20 cm/min to 30 cm/min SMAW: 20 cm/min to 40 cm/min
Welding atmosphere	Argon, 15 to 25 L/min

(A) GTAW: gas tungsten arc welding.
(B) SMAW: shielded metal arc welding.
(C) DCSP: direct current straight polarity.
(D) AC: alternating current.