Experimental study to improve the stability of district heating pipe

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Introduction

The district heating systems distributes the heat generated from a cogeneration plant to wider locations. The heating pipes (DHPs) consist of three major parts, namely, carrier pipe (steel), polyurethane (PUR) insulator, and high-density polyethylene (HDPE) casing. The district heating pipes (DHPs) are laid under the ground and normally work under water temperature ranging from 10 to 120℃ and an internal pressure of around 16 kg·f/cm^2. As a result, DHPs are subjected to internal loadings. Frictional interactions between the pipes and soil contribute to the external loadings on the pipes. Thus, investigation on the principles of failure mechanisms of DHPs will help in ensuring the mechanical stability and reliability.

An earlier investigation by Kim et al. [1] on the reliability of DHPs under thermo-elastic fatigue loading using finite element analyses suggested that by changing the thickness of carrier pipe one can avoid the implementation of foam pad that are conventionally used for the safety design of bend parts. As a result, shear stress limits of PUR were still observed to be within the safety limits of standard pipe sizes of 125A and 200A. However, their results were limited to bend region of the pipe. This experimental investigation is focused to the straight DHP parts where the influence of compressive loading on the mechanical properties becomes crucial for the reliable design. Hence, pipes with varying standard thickness, namely, 125A and 200A, are studied. Previous studies have indicated that the thicker carrier pipe of large DHPs (400A, 800A) are less effective in maintaining the shear strength of PUR, hence, our study considers only 125A and 200A pipe standards.

Experimental

Subjects of the Experiment

A guidebook is employed for standard specifications of DHPs and is listed at Table 1[3]. In addition, Table 2 shows thickness difference of SCH 20 and SCH 60. These specifications were used in designing the pipes as shown in Fig. 1. Figs. 1 (a) and (b) shows pipe samples used for this investigation. Fig. 1(c) shows the Universal testing machine along with the specially designed sample holding jigs and pipe part.

Testing Machine and Procedure

The compressive loading experiment was carried out in Universal test machine (UTM). The crosshead speed was adjusted to 5mm/min (displacement control) and the data recorded for every 40mm displacement.

Table 1 Dimensions of DHPs both 125A and 200A

Unit(mm) \ Size		125A	200A
Carrier pipe	D_i	129.6	203.5
	D_o	139.8	216.3
	Thickness	5.1	6.4
PUR Thickness		39.1	43.8
HDPE	D_i	218.0	303.8
	D_o	225.0	315.0

Table 2 Dimension of carriers both SCH 20 and 60

Size	Carrier thickness (mm)	
	SCH 20	SCH 60
125A	5.1	8.1
200A	6.4	10.3


(a)


(b)

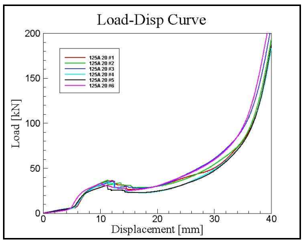
(c)

Fig. 1 The experimental apparatus (a) The side view of the specimen (b) The top view of the specimen (c) Universal test machine

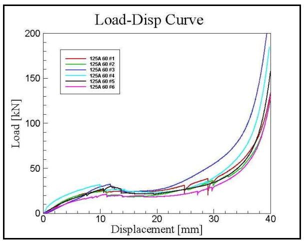
Experiments are performed 6 times on each of 125A (SCH 20, 60) and 200A (SCH 20, 60) pipe. Thus, average result of load vs. displacement curve can be used to determine the fracture point of PUR.

Results and Discussion

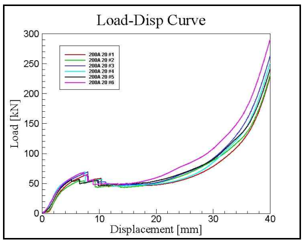
Fig. 2 shows the load-displacement curve for all the experimental cases discussed above. As mentioned earlier, fracture of PUR can be confirmed from these plots and is mentioned in Table 3.



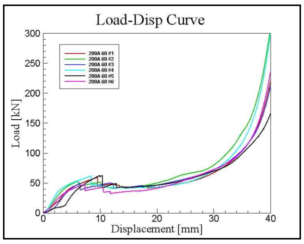
(a) 125A SCH 20



(b) 125A SCH 60



(c) 200A SCH 20



(d) 200A SCH 60

Fig. 2 Load - Displacement Curve


(a) 125A SCH 20


(b) 125A SCH 60


(c) 200A SCH 20


(d) 200A SCH 60

Fig. 3 Specimens after compressive loading experiment

It is observed from Fig. 3 and Table 3 that for pipes with large thickness have low load bearing capacity for PUR fracture. This can be explained as follows. The moment of inertia (I) and cross section area of pipe increases as the carrier pipe thickness increases as can be understood from Eq. 1. This results in a large deformation at low load on SCH 60. Consequently, this can be related to the amount of stress generated in PUR foam as in Eq. 2.

Table 3. Load and displacement at fracture of PUR under different pipe thickness.

Samples		The point of fracture on PUR	
		Load (kN)	Displacement (mm)
125A	SCH 20	34.10	11.55
	SCH 60	27.57	11.11
200A	SCH 20	63.67	7.26
	SCH 60	55.45	7.96

Since the presence of PUR ensures the thermal stability to DHPs, fracture may decrease the heat supply efficiency. Hence, the mechanical reliability of PUR part is considered significant as it affects both the mechanical reliability as well as thermal stability of DHPs.

$$I = \frac{1}{32}\pi\left(d_{out}^4 - d_{in}^4\right) \quad (1)$$

$$\text{Stress } (\sigma) = \text{Modulus of elasticity} \times \text{Strain } (E\varepsilon) \quad (2)$$

Conclusion

This paper reports on the stability and reliability of straight DHPs. Although the increase in thickness of carrier pipe helps in maintaining the stability of carrier pipes, it may result in PUR fracture. Experimental investigation shows that as the pipe thickness increases load-bearing strength of PUR decreases resulting in a PUR fracture at low load. In conclusion, increasing the thickness of carrier pipe is not recommended in straight DHPs as this may trigger PUR crack. This is in contrast to the bend region where the increase in carrier pipe thickness has a positive influence on the safety design.

Acknowledgement

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References

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