Effects of Weldment on CTOD and J-integral Estimations of Gas Pipeline with a Circumferential Surface Crack under Large Displacements

Y. Y. Jang[1], J. Y. Kang[1], N. S. Huh[1*], I. J. Kim[2] and Y. P. Kim[2]

[1]Dept. Mechanical System Design Engineering, Seoul National Univ. of Science and Technology, Seoul, Korea
[2]Gas Infrastructure Research Division, Korea Gas Corporation Research Institute, Ansan, Korea

*Corresponding author: nam-su.huh@seoultech.ac.kr

1. Introduction

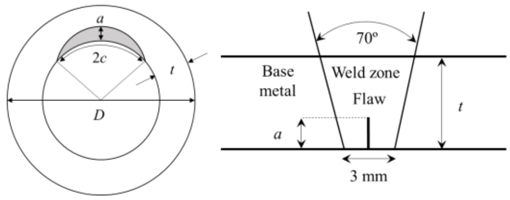
As energy demand increases, the need of transportation pipelines also increases to safely supply oil or natural gas. Pipelines are usually manufactured with a number of short pipes joined by circumferential welding. The girth welds may contain weld imperfections, which have a potential to develop planar crack. For this reason, it is important to assess the structural integrity of the pipelines with crack in weldment and use a suitable fracture assessment procedure.

Strain-based design assessment has been known for suitable assessment concept for pipelines subjected to displacement-controlled load and high plastic deformation rather than conventional stress-based design assessment. Tensile strain capacity (TSC) has been used for one of essential elements to indicate limit state in strain-based design. For a pipeline with a crack, TSC based on fracture mechanics can be determined by adopting elastic-plastic fracture parameters. Crack-tip opening displacement (CTOD) and *J*-integral have been typically used for elastic-plastic fracture parameters. However, the strength mismatch between base metal and weld metal strongly influences CTOD and *J*-integral, and it complicates TSC assessment. Moreover, to assess TSC for various geometries and crack shape, CTOD and *J*-integral solutions of pipeline with a crack in weldment, especially a girth weld crack highly are required.

In the present study, CTOD and *J*-integral solutions of pipelines with a surface crack in girth weld are proposed. For this purpose, FE analyses were systematically carried out by considering various pipe geometries and material properties. Moreover, the effect of strength mismatch of weldment on CTOD and *J*-integral of cracked pipe was investigated.

2. Geometries and FE analyses

Fig. 1 shows schematics of cross-section of surface crack and girth welding configuration. In Fig. 1, *a*, 2*c*, *t* and *D* denote the crack depth at the deepest point, the circumferential crack length, pipe thickness and outer diameter of pipe, respectively. Material properties are characterized by yield strength (*Y*), tensile strength (*T*) and strength overmatch factor (OM). OM is defined as



(a) (b)

Fig.1 Schematics of cross-section of surface crack and girth welding configuration

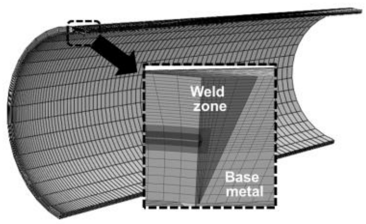


Fig.2 FE model of pipe with a circumferential surface crack in girth weld

Table 1 FE analysis matrix for parametric study

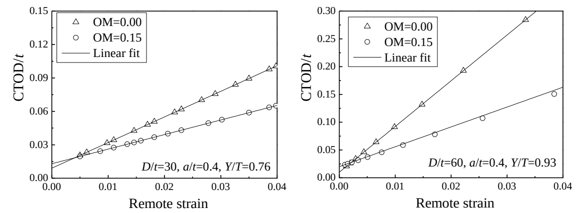
D/t	*a/t*	*a/c*	*Y/T*	OM
30, 60	0.2, 0.4	1/8	0.76, 0.93	0.00, 0.15

a ratio of difference of tensile strength between base and weldment ($(T_{weld}-T_{base})/T_{base}$). In this study, *Y* of based metal is fixed to be 550 MPa. The strain-stress curves used in parametric study has been represented by the equation given in CSA Z662 [1]. The FE analysis matrix for parametric study was summarized in Table 1.

In Fig. 2, a quarter of the pipe with a circumferential surface crack in girth weld was modelled considering the symmetric condition. As for loading condition, the axial displacement was applied at the end of pipe section.

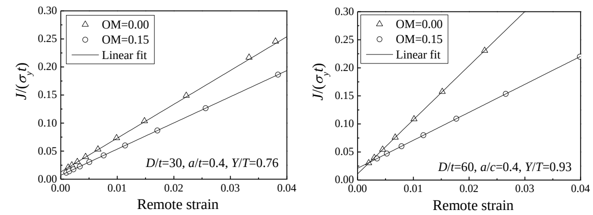
The FE analysis was performed by using ABAQUS 6.18 implicit solver. The nonlinear geometric analysis procedure was employed to consider geometric nonlinearity due to large plastic deformation at crack-tip region. Linear element was used, and the number of elements and nodes in FE model was 100,429 and 110,412, respectively.

In this study, definitions of CTOD based on original crack-tip concept was considered. The CTOD is calculated from a double clip-gage arrangement by using the homothetic triangle



(a) (b)

Fig.3 Strain-based CTOD estimation of pipes with a circumferential surface crack in weldment



(a) (b)

Fig.4 Strain-based *J*-integral estimation of pipes with a circumferential surface crack in weldment

Table 2 Values of a_1 and a_2 for CTOD estimations of surface crack in weldment

OM	*Y*/*T*	*D*/*t*	a/t	$a_{1,}$	a_2
0.00	0.76	30	0.2	1.033	0.007
			0.4	4.404	0.011
		60	0.2	1.055	0.010
			0.4	4.096	0.017
	0.93	30	0.2	1.382	0.009
			0.4	10.286	0.011
		60	0.2	1.309	0.013
			0.4	8.230	0.010
0.15	0.76	30	0.2	0.638	0.005
			0.4	2.606	0.009
		60	0.2	0.648	0.009
			0.4	2.595	0.014
	0.93	30	0.2	0.694	0.005
			0.4	3.931	0.018
		60	0.2	0.702	0.009
			0.4	3.575	0.020

Table 3 Values of b_1 and b_2 for *J*-integral estimations of surface crack in weldment

OM	*Y*/*T*	*D*/*t*	a/t	$b_{1,}$	b_2
0.00	0.76	30	0.2	1.561	0.002
			0.4	6.122	0.013
		60	0.2	1.669	0.001
			0.4	6.307	0.014
	0.93	30	0.2	1.578	0.008
			0.4	10.966	0.016
		60	0.2	1.627	0.007
			0.4	9.642	0.011
0.15	0.76	30	0.2	1.105	0.000
			0.4	4.664	0.007
		60	0.2	1.101	0.000
			0.4	4.750	0.007
	0.93	30	0.2	0.974	0.001
			0.4	4.906	0.029
		60	0.2	0.983	0.001
			0.4	4.986	0.021

theory [1].

To calculate crack driving force as a function of remote strain (ε) from FE analysis, uniform strain zone on the outer surface along pipe length should be defined. Uniform strain zone can be found away 1.5D from location of crack face, in which remote strain of the pipe was estimated with gage length of 0.5 times outer diameter.

3. Results

Figs. 3 and 4 show the FE results of CTOD and *J*-integral with increasing remote strain. As shown in Figs. 3 and 4, as strength of weldment increases, CTOD and J-integral decreases. Moreover, CTOD and *J*-integral have linear relation with respect to remote strain. To estimate CTOD and *J*-integral, the linear regressions were made based on FE results by using least squares method as follows

$$\mathrm{CTOD}/t = a_1\, \varepsilon + a_2 \quad (2)$$

$$J/(\sigma_y t) = b_1\, \varepsilon + b_2 \quad (3)$$

The values of a_1, a_2, b_1 and b_2 for geometries and material properties are summarized in Table 2 and 3.

4. Concluding Remarks

In this study, CTOD and *J*-integral solutions of pipelines with a surface crack in girth weld are proposed. For this purpose, parametric FE analyses for various geometries, material properties were carried out. Based on FE results, it can be shown that CTOD and *J*-integral decreases as strength of weldment increases. The present results can be used to assess TSC of pipeline with surface crack in weldment.

Acknowledgment

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References

[1] Y. Y. Jang, J. Y. Kang, N. S. Huh, I. J. Kim and Y. P. Kim, Predictions of tensile strain capacity for strain-based pipelines with a circumferential and internal surface flaw, *Proceeding of the ASME 2019 International Conference on Ocean, Offshore and Arctic Engineering*, (2019), OMAE2019-96480.