Effects of Defect Size on Crush Test Load of Butt Fusion Welded MDPE Pipes

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Abstract - It is expected that the size of welding defect affects the mechanical performance of welded medium density polyethylene (MDPE) pipe joints. In this study, butt fusion welded MDPE pipe joints with a single spherical or planar defect of various sizes were studied using experimental crush testing and also by finite element method. The crush test showed that the mechanical performance of crush was not affected by the size and geometry of a single welding defect when the defect size was increased to 45% of the pipe’s wall thickness. The simulation results indicated that the effect of the single welding defect on the Von Mises stress distribution near the defect explained the reason of the test results.

Key words : MDPE; Polyethylene; Welding defect; Crush test

1. Introduction

Butt fusion welding is a simple and effective welding method for polyethylene pipes [1-3]. Medium density polyethylene (MDPE) pipes for gas distribution are widely joined by butt fusion welding to construct a good airproof and structurally sound pipe system. The quality and integrity of the pipe system are dependent on the welded joints, while the quality and integrity of the welded joints are dependent on the hot tool-surface temperature, the heating period, and the magnitude of axial force applied during the welding process [3-6]. If the process conditions are judiciously designed, mechanical properties such as yield strength, elongation at fracture, and fatigue life traversing the welded joints are not decreased by the welding process [7,8]. The integrity of the welded joints is generally affected by welding defects [9]. Previous studies investigated detailed the effects of welding defects on the tension and burst performances of the welded MDPE pipe joints [10,11]. Besides these, a pipe system is also potentially subject to complex loading conditions including tension, bend, crush, and creep [12]. For this reason, previous studies are not enough for evaluating the effects of welding defects on the mechanical performance in welded joints. In order to establish a reliable evaluation of pipe system integrity, the effects of welding defects on welded MDPE pipe joints under different loading conditions need to be further studied.

In this study, effects of butt fusion welding defect size on the short-term mechanical performance of welded MDPE pipe joints were studied using a crush test. Finite element analyses were also conducted to investigate the stress distribution near the defect in the crush test specimens.
2. Experimental Crush Testing

The sizes [outside diameter (O.D)] of the MDPE pipes used in this study were 110, 225, and 315 mm, respectively. The standard dimension ratio (SDR) that the ratio of the O.D to the thickness (t) was 11. The material density and melt flow index were 939 kg/m³ and 0.2 g/10 min, respectively. The yield stress was 18.6 MPa. Pipe joint manufacturing using butt fusion welding was conducted according to the ISO 21307 standard [13]. Defects were artificially inserted at the center of the butt-weld surface before heating for fusion. Figure 1 (a) ~ (d) shows steps for inserting a defect in the MDPE pipe. The defects were made of steel in two different geometries, i.e., planar and spherical defects, as shown in Fig. 1(c). The dimensions of all defects and pipes are shown in Table 1. The ratios of the defect size to the pipe wall thickness were 15%, 30%, and 45%, respectively.

The crush test is shown in Fig. 2. The specimen length was 4 times the O.D. The width of the platen was 30 mm. The applied displacement speed of the loading pin and the platen was 20 mm/min, and the displacement and load were recorded during the tests. Three identical specimens were tested for each size of the welded MDPE pipe joints. Therefore, tests were conducted in twenty-one specimens for each pipe size as shown in Table 1 (2 defect geometries × 3 defect sizes × 3 specimens + 3 specimens without defects). Three pipe sizes were studied. Hence, a total of 63 specimens were used for the crush test.

The welded joint with welding bead and a single
welding defect was located in the middle of the specimen for all specimens undergoing the crush test. The single welding defect was located in the 12 o’clock position for all specimens. All tests were carried out at room temperature.

3. Finite Element Modeling

Various effects of the defect sizes on stress distribution in the crush test specimens were investigated by finite element method. Finite element simulation was conducted using Abaqus version 6.11. Three-dimensional models of the specimens with 110 mm O.D were used. Spherical and planar geometries were employed as the spherical and planar defects, respectively. Since the defect made of air was more influential than that made of steel under a compression condition [14] and the defect region of the specimen was suffered a compression load, the defect composed of air was used in these simu-
Table 2. Dimensions and geometries of the defects in the simulated crush specimens

<table>
<thead>
<tr>
<th>Pipe Size</th>
<th>Planar Defect (Height = 1 mm)</th>
<th>Spherical Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Diameter (mm)</td>
<td>Thickness (mm)</td>
<td>Width × Length (mm × mm)</td>
</tr>
<tr>
<td>110</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0 × 3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.0 × 6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.0 × 9.0</td>
</tr>
</tbody>
</table>

Fig. 3. Finite element model of a quarter of the crush test specimen with 110 mm O.D and a spherical defect whose size is 60% of the thickness.

As shown in Table 2, the defect sizes used for the simulations were 30%, 60%, and 90% of the thickness. Considering the geometrical symmetry of the specimen, only a quarter of the specimen was modeled.

One of the typical specimen models is shown in Fig. 3. This model consisted of a spherical defect. The supporting pin was an analytical rigid shell. Symmetry boundary conditions were applied to the symmetry planes. Load application was simulated by suffering pressure in the welding bead as shown in Fig. 3(a part in red color). Element of C3D20R (20-node quadratic brick, reduced integration) was employed. The whole specimen was assumed to be homogeneous MDPE with a Young’s Modulus of 1.1 GPa and Poisson’s ratio of 0.3. The nonlinear elastic-plastic behavior obtained from the MDPE tensile specimen was used [10].

4. Results and Discussion

4.1 Crush test results

The measured load-displacement curves are shown in Fig. 4 for the specimen with 110 mm O.D. For the no defect specimens, as shown in Fig. 4 (a), the applied load increased slowly to a knee point with increased the displacement first. And then a steady state stage was reached; the load increased steadily with increased the displacement at this stage. Finally, the load increased rapidly even though the displacement almost kept a constant; the upper and lower inner wall surface were contacted together under this final stage as shown in Fig. 2 (b). The curves of the spherical and planar defect specimens were almost same as those of the no defect specimens, even when the defect size was increased to 45% of the thickness as shown in Fig. 4 (b) ~ (g). Since the results obtained from the 225 and 315 mm O.D pipes showed the same trend as that shown in Fig. 4, their results were not shown in this paper. Therefore, neither the spherical nor the planar defects affected the mechanical performance of crush for welded MDPE pipe joints even when the defect size was increased to 45% of the thickness. Appropriateness of the location of defect was previously explained [14].
Fig. 4. Crush test results of the specimens with 110 mm O.D.
Fig. 5. Comparison of the Von Mises stress distribution near the welding bead region among the no defect specimen, spherical defect specimens with defect sizes of 30% and 90% of the thickness.
4.2 Von Mises stress distribution near the welding defect

Von Mises stress distribution near the welding bead region are shown in Fig. 5 for the no defect specimen and spherical defect specimens with defect size of 30% and 90% of the thickness. As shown in Fig. 5 (a), the maximum stress appeared in the A and B region for the no defect specimen when the two inner surfaces had the distance of 32 mm and 0 mm, respectively. For the spherical defect specimen with defect size of 30% of the thickness, Fig. 5 (b) shows that the maximum stress appeared in the A and B region when the two inner surface had the distance of 32 mm and 0 mm, respectively the defect affected on the stress distribution was insignificant. When the defect size was increased to 90% of the thickness, Fig. 5 (c) shows that effect of the defect on the stress distribution was also ignorable when the two inner surface had the distance of 32 mm; but the B region of the maximum stress moved to the defect region and made the defect region had larger stress when the two inner surface contacted together. The effect of the planar defect on the stress distribution near the welding bead region was similar as the spherical defect such as shown in Fig. 6 for the planar defect specimen with defect size of 90% of the thickness. Therefore, the effect of defect on the stress distribution near the welding bead could not affect the failure, especially when then defect size was smaller than 30% of the thickness. Consequently, the load-displacement curves in Fig. 4 were not changed as the defect size was increased regardless of the defect shape.

The tension test, burst test, and crush test are short-term tests. They can only test the short-term mechanical performance of polyethylene pipes. Based on the previous research [10,11] and this paper, we can argue that the welded MDPE pipe joint with a single welding defect may be acceptable temporarily for short-term application under the tension, inner pressure, and crush loadings, if the maximum defect size is less than 15% of the thickness.

5. Conclusions

Butt fusion welded MDPE pipe joints with a single defect of various sizes of spherical and planar defect were investigated using a crush test and by finite element method. The following conclusions are obtained:

(1) The crush test showed that the resistance of welded MDPE pipe joints to the crushing was not affected by the welding defect size and...
geometry of the single welding defect when the defect size was increased to 45% of the thickness.

(2) The simulation results showed that the defect effects on the stress distribution of the specimen was small, even when the defect size was up to 30% of the thickness.

(3) Based on the previous studies and these results, it can be argued that the short-term mechanical performance of the welded MDPE pipe joints cannot be affected by a single welding defect under the tension, inner pressure, and crush loadings, if the maximum defect size is smaller than 15% of the thickness.

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