Ductile Fracture of Circumferentially Cracked Piping under Bending Load

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ABSTRACT
The unstable fracture of piping with a crack will only occur after the applied load pass the maximum value and if unstable condition related to the piping system compliance etc. is satisfied. The prediction of the maximum value(the maximum moment) is necessary to prevent the unstable fracture by the simple procedure. The maximum moment is conservatively predicted by the following procedure.
(1)The maximum moment is evaluated using the net-section collapse criterion and the flow stress obtained from the specified S_y and S_u in MITI Notification No.501 for the through-wall cracks and part-through cracks up to the crack depth of 70% wall thickness. (2)The part-through crack, whose depth is beyond 70% of wall thickness, is treated as the through-wall crack.

1. INTRODUCTION

The ductile fracture tests of circumferentially cracked piping were performed as a part of the piping reliability demonstration test program. The purpose of these tests is to clarify the fracture behavior of cracked piping under four point bending load and to establish the fracture criterion

2. TEST PROCEDURE

The tests are carried out using 3, 6 and 12 inch diameter pipes of Type 304 stainless steel and STS 42 carbon steel without and with a welded joint. Circumferential through-wall and part-through cracks were machined at the center of the test pipes. The welded joints were manufactured by GTAW(gas tungsten-arc weld procedure) or SMAW(shielded metal-arc weld) for 6 inch or 12 inch stainless steel pipes, respectively. SMAW was used for manufacturing all welded joints of carbon steel pipes. The tests were performed at RT, 300 ℃ and satulated temperature, 285 ℃ of 6.8MPa. 6 and

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12 inch pipes were tested using 400 kN and 1500 kN bending facilities, respectively. 3 inch pipe was tested using 1000 kN material test machine(Yasuda et al.1988;Tyujyo et al.1987). The moment -rotation curve was measured for each test pipe. The mechanical properties of pipe materials were obtained by tensile tests and the flow stresses were obtained from the tensile test results. The flow stress is defined by 1/2(yield strength plus tensile strength).

3.TEST RESULTS

The unstable fracture occurred after the load passed the maximum point of the moment-rotation resistance curve, and when unstable condition related to the piping system compliance and the slope of resistance curve etc is satisfied. In order to protect ductile unstable fracture in the simple procedure, the prediction of the maximum moment of circumferentially cracked piping is important. The extent of influence of temperature on the maximum load of circumferentially cracked pipe is nearly same with that on the flow stress of the pipe materials. The pressure of 6.86 MPa reduces the maximum moment of test pipes with through-wall crack about 10% in case of 60 or 90 degrees . The amount of reduction of maximum moment is near to the amount of the prediction by the net-section collapse criterion. The net-section collapse criterion gives the good prediction of the fracture moment for stainless steel and carbon steel pipe with a through-wall crack. While, the net-section criterion gives the trend of prediction diffrent from the trend of the experimental results. Especially, it gives unconservative prediction for test pipes with a part-through crack whose depth is over 75% of the wall thickness.

4.DISCUSSION

The experimental results were discussed in order to propose the conservative prediction method of the ductile fracture.

Figures 1 and 2 show the the ratio of the experimental value of the maximum moment, M_o of through-wall cracked stainless steel and carbon steel pipes versus nondimensional crack angle, $2\theta/2\pi$. Theoretical curves are also indicated in these figures. It is clear that the maximum moment of through-wall cracked pipe is conservatively evaluated. In conclusion, the NSCC is available up to 12 inch diameter pipe. Figures 3 and 4 shows the ratio of the experimental result, M_{exp} to the predicted value, M_{pred} of maximum moment of part-through cracked stainless steel and carbon steel pipes versus nondimensional crack depth, d/t. The ratio of the maximum moment is above 1.0 when the ratio d/t is lower than 0.7. However, the ratio is below 1.0 when d/t is higher than 0.7. Therefore, the crack which is deeper than 70% of wall thickness should be evaluated as a through wall crack with the same crack angle.

The effect of pipe diameter is discussed using test results of 3, 6 and 12 inch pipes as follows. The ratio of the experimental maximum moment to the prediction decreases with increase of pipe diameter and may become below 1.0 in case of large diameter pipe. As the pipe up to 30 inch diameter is used in LWR coolant circuit piping, the correction factor of the prediction by NSCC is necessary. The availability of Z factor(ASME Code Sec.XI,1989) and G factor(NUCLEAR ENGINEERING TEST CENTER,1989) was investigated for stainless steel and carbon steel pipes, respectively as indicated in Figs.5 and 6. As the values,1/Z and 1/G show the same trend with the trend of the experemental results against pipe diameter. These values can be used as the correction coefficient.

5. CONCLUSION

The prediction procedure of the maximum moment was investigated based on ductile fracture tests of circumferentially cracked piping subjected to four point bending load. The maximum moment is conservatively predicted by the following procedure.

(1)The NSCC should be used for the through-wall crack and the part-through crack when d/t is below 0.7. The flow stress is obtained from the specified S_y and S_u in the MITI Notification No.501 in the procedure.

(2)The part-through crack should be treated as the through-wall crack when d/t is above 0.7.

(3)The influence of pipe diameter should be evaluated using Z-factor for stainless steel pipes and G factor for carbon steel pipes.

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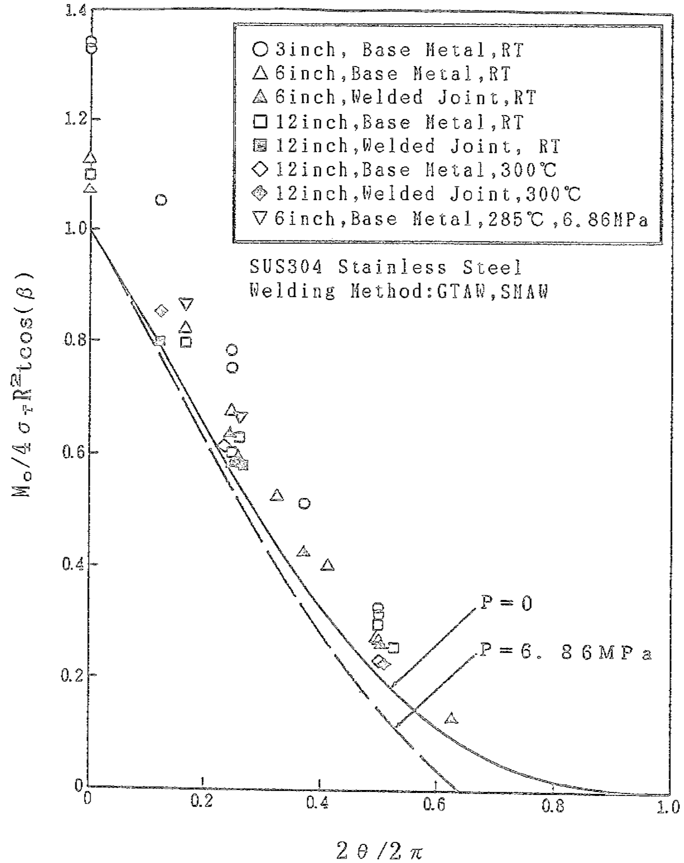

Fig. 1 Comparison of fracture moment of through-wall cracked stainless steel pipe between the experimental results and the prediction by the net-section collapse criterion

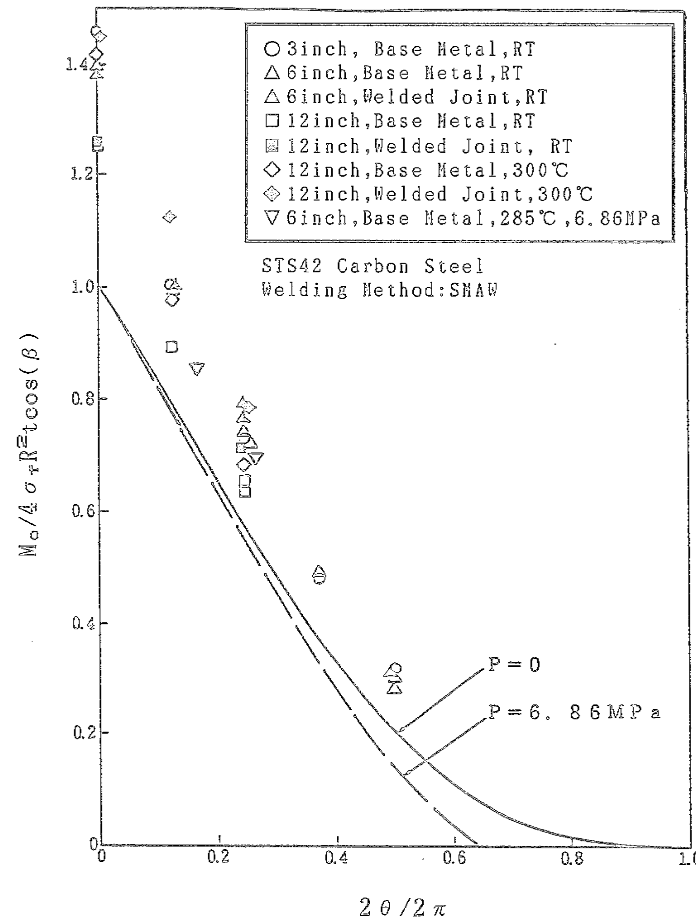

Fig. 2 Comparison of fracture moment of through-wall cracked carbon steel pipe between the experimental results and the prediction by the net-section collapse criterion

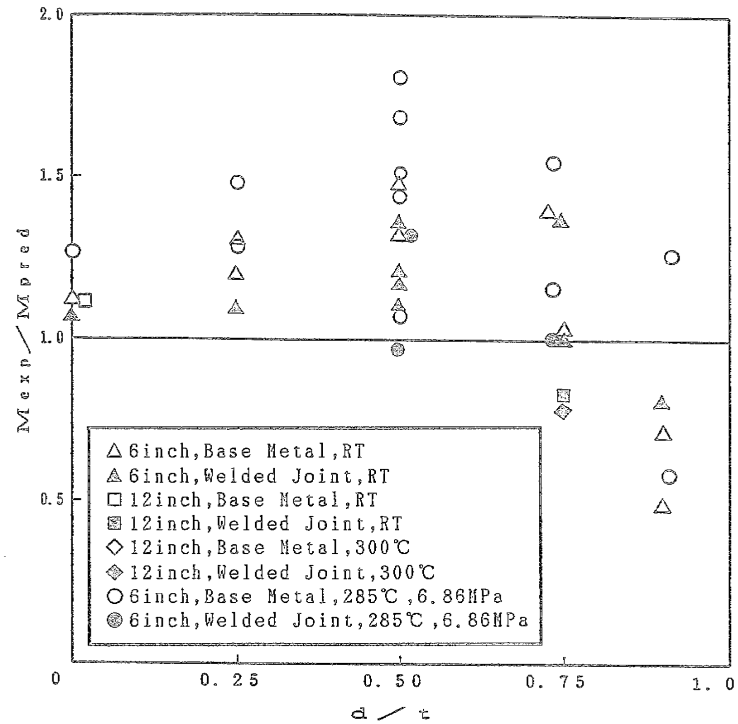

Fig. 3 Comparison of fracture moment of partially cracked stainless steel pipe between the experimental results and the prediction by the net-section collapse criterion

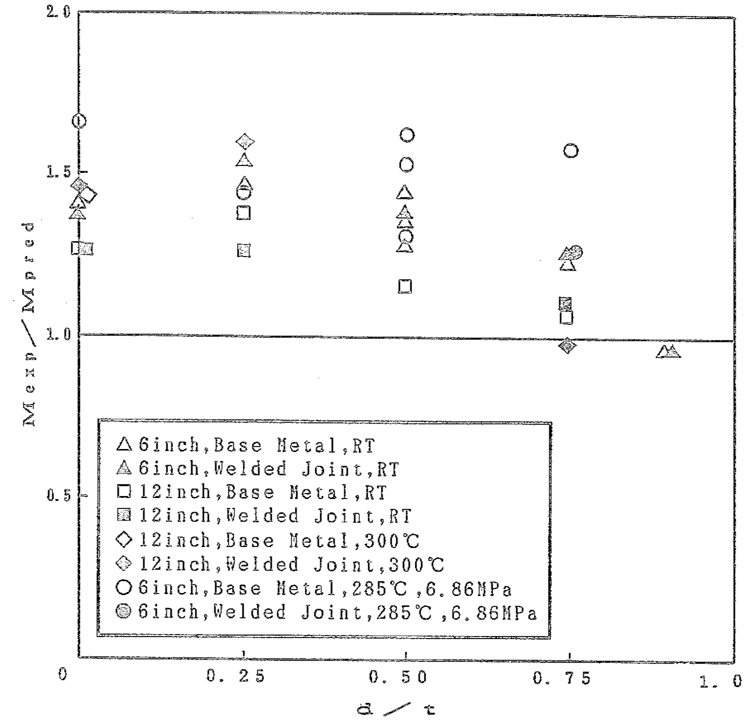

Fig. 4 Comparison of fracture moment of partially cracked carbon steel pipe between the experimental results and the prediction by the net-section collapse criterion

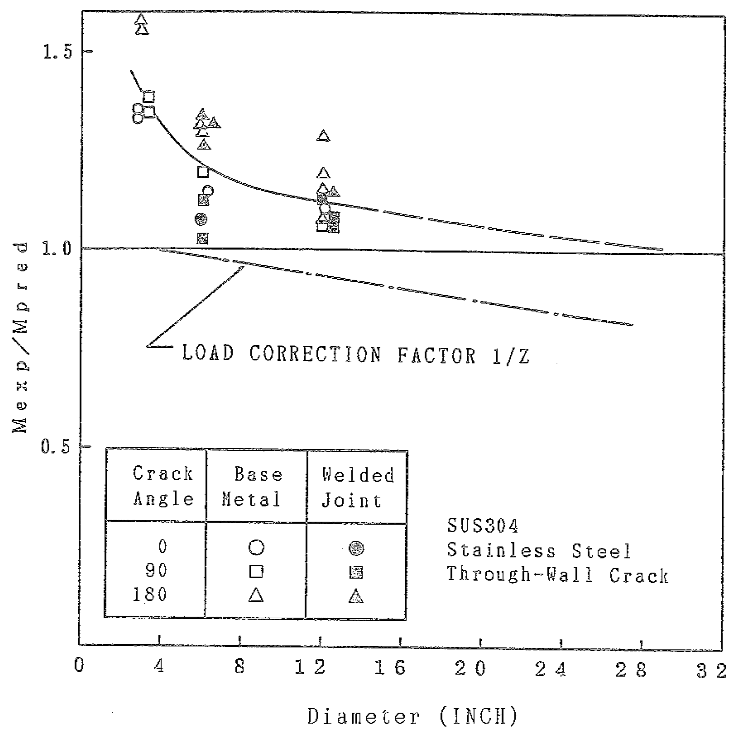

Fig. 5 Effect of pipe diameter on the fracture moment of through-wall cracked stainless steel pipe

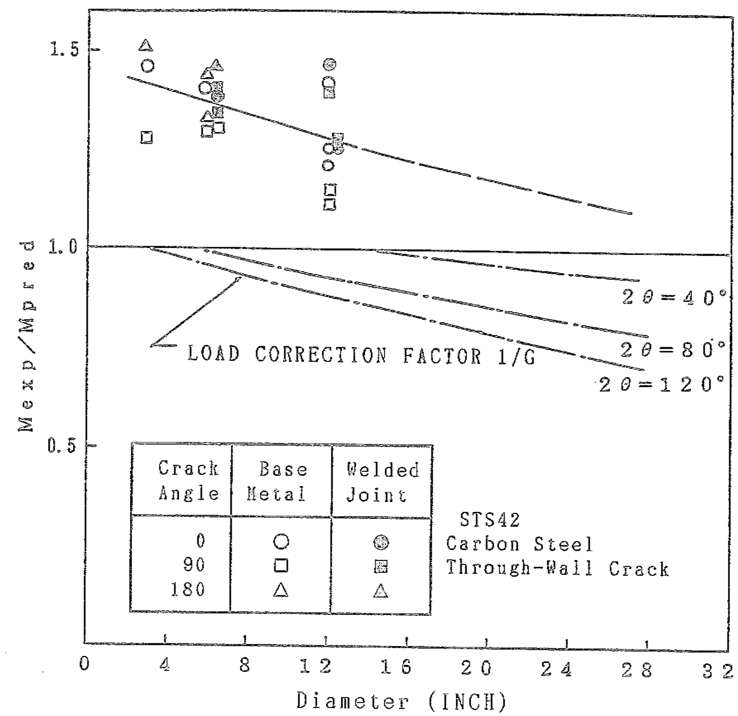

Fig. 6 Effect of pipe diameter on the fracture moment of through-wall cracked carbon steel pipe