High Cycle Fatigue Strength of Butt Welded Joints of Small Diameter Pipes

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ABSTRACT

Fillet welds are usually used for joints of small piping lines with 2-inches nominal outer-diameter or smaller. The fillet welded joints might not be enough strong to withstand the high cycle fatigue produced by steady-state vibrations, because they have inherent crack-like discontinuities in the root portion. The fatigue strength of butt welded joints is believed to be higher than that of the fillet welded joints, so that it is desirable to use the butt welded joints for small piping lines under steady-state vibrations. However, there is no available data of high cycle fatigue strength of small diameter piping butt welded joints. This paper presents new data of high cycle fatigue strength of butt welded joints in the small diameter pipes and development of their fatigue strength reduction factors for design use.

1 INTRODUCTION

Fillet welds are usually used for joints of small piping lines with 2-inches(50.8mm) nominal outer-diameter or smaller. The fillet welded joints might not be enough strong to withstand high cycle fatigue produced by steady-state vibrations, because they have inherent crack-like discontinuities in the root portion. Fatigue strength of butt welded joints is believed to be higher than that of fillet welded joints. It is desirable that we need to make sure how much fatigue strength butt welded joints have to use them for small piping lines under steady-state vibrations. Rodabaugh and Moore surveyed fatigue test data of butt weld joints of pipes to review CK products for use in the ASME Boiler and Pressure Vessel Code [1]. Pipe outer-diameter of the test data that they did was not smaller than 4 inches. Recently, Otha et al. conducted bending fatigue tests of butt welded pipes with 2-inches outer-diameter[2]. However, their test data did not cover high cycle range of over 10^6 cycles, corresponding to steady-state vibrations. Review for the earlier research on the fatigue tests of butt welded pipes indicates that there is no available data of high cycle fatigue strength with over 10^6 cycles on 2-inches outer-diameter or smaller butt welded pipes.

This paper presents new test data of high cycle fatigue strength of butt welded joints in small outer-diameter pipes and development of their fatigue strength reduction factors for design use.

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2 EXPERIMENTS

2.1 Specimens and experimental procedure

Materials used for the experiments were Type 316L austenitic stainless steel and STS42 carbon steel which are usually used in nuclear power plants. Stainless steel specimens were fabricated from a 40mm diameter bar, and carbon steel specimens were did from a 436.2mm outer-diameter, 36.3mm wall thickness STS42 pipe. Each specimen was 27.2mm outer-diameter and had a butt welded joint in the center. The welded joints were made by manual gas tungsten arc welding. We tried to control height of weld reinforcement on the inner and/or outer surface to know how much effect the height of the reinforcement gives to fatigue strength. Also we prepared Schedule 40 and 80 wall thickness specimens for Type 316L, and Schedule 80 and 160 wall thickness specimens for STS42 to identify whether difference of wall thickness would impact fatigue strength. Figure 1 shows specimen geometry and details of welded joints. As shown in Figure 1, specimens were classified according to the height of the reinforcement. If the reinforcement on the outer side, H_o , is approximately equal to 1.5mm or higher, specimen is called Large Outer Reinforcement. If the height on the inner side, H_i , is so, specimen is called Large Inner Reinforcement. Specimen is called Usual Weld in case that both of H_o and H_i are less than the limitations as described above. Fatigue tests were conducted at room temperature in the air. Stainless steel specimens were subjected to rotatinal bending load or axial load with stress ratio, R (minimum stress/maximum stress) = -1. While, carbon steel specimens were subjected to just only rotatinal bending load.

2.2 Results of experiments

Observation of the whole specimens after the experiments indicated that a crack initiated at toe of the inner weldments for Usual Weld and Large Inner Reinforcement, while it did at toe of the outer weldment for the Large Outer Reinforcement.

Fatigue strength was summarized as relation between applied nominal stress amplitude, S_a and fatigue life, N_f . Figures 2, 3 and 4 show the fatigue strength of stainless steel butt welded joints under rotatinal bending load, the same welded joints under axial load, and carbon steel butt welded joints under rotatinal bending load, respectively. It can be seen from Figures 2 and 4 that the fatigue strength of Large Outer Reinforcement is close to that of Usual Weld. Figures 2 and 3 indicate that Large Inner Reinforcement gives 20 to 30 percents lower fatigue strength than Usual Weld. It can be found that there are some effects due to difference of wall thickness for stainless steel in Figure 2 but not for carbon steel in Figure 4. The data in Figure 2 indicate that the fatigue strength of Schedule 40 wall thickness specimens of Usual Weld is 20 to 30 percents lower than that of Schedule 80, and close to that of Large Inner Reinforcement.

The figures also presents comparisons of the data with a curve fitting to Jaske and O'Donnell data [3] with the Modified Goodman method for stainless steel, and a curve fitting to our data using STS42 smoothed bar specimens. These comparisons indicates that all of the butt welded joints give lower fatigue strength than the corresponding base metals.

2.3 Significance of the results

A crack initiated at toe of the inner side of the whole specimens for Usual Weld subjected to rotational bending load. A nominal stress due to applied bending load is always higher on the outer surface than that on the inner surface. It can be believed that the reason why crack initiation happened at toe of the inner surface is effect of mean stress due to welding residual stress, because residual stress is usually tensile on the inner side and compressive on the outer surface after butt welding of a small size pipe. The welding residual stress may give impact on the experimental results that the fatigue strength of Large Outer Reinforcement is close to that of Usual Weld, and that of Large Inner Reinforcement is unexpectedly lower. Anyhow, we need to take more note of height of the inner reinforcement to make butt welded pipes higher quality, because the fatigue strength is more sensitive to height of the inner reinforcement.

The results showed that the apparent fatigue strength of Schedule 40 wall thickness specimens of Usual Weld is lower than that of Schedule 80 for stainless steel. We took stress amplitude as an applied stress on the outer surface of each specimen to evaluate fatigue strength. It means that an applied stress on the inner surface of Schedule 40 specimen is obviously higher than that of Schedule 80 Specimen, if both stress amplitude is the same. That is reason the apparent fatigue strength of Schedule 40 specimens is lower than that of Schedule 80.

The comparisons of the welded joints data to the polished bar data indicated that all of the butt welded joints give lower fatigue strength than the corresponding base metals. It requires to develop fatigue strength reduction factor for design use.

3 DEVELOPMENT OF FATIGUE STRENGTH REDUCTION FACTOR

Fatigue strength factor, K_f was developed in the comparison of each experimental data to the curves shown in Figures 2, 3 and 4. K_f is originally defined by ratio of fatigue strength of base metal using smoothed bar specimen to that of butt welded joints. As described above, the case of the carbon steel is consistent with the original definition, but not the stainless steel. The reason why Jaske and O'Donnell data with the Modified Goodman method were used here is that their data give basis to Curves B and C in ASME B&PV Code Section III, Appendix I and the comparisons are more useful to piping designers. K_f values are plotted by log-log scale as a function of fatigue life, N_f in Figures 5 and 6. The figures indicates that it is reasonable to take the fatigue strength reduction factor as 2 for Schedule 80 or larger wall thickness, butt welded pipe without the large inner reinforcement, and 2.5 for the case of large inner reinforcement or Schedule 40 wall thickness.

4 SUMMARY

The experimental results described above are appealing in that the fatigue strength of the butt welded pipes is more sensitive to height of the inner reinforcement and may be given by the effect of welding residual stress. The experimental data supported the development of the fatigue strength reduction factor of the butt welded pipes which are used under steady-state vibrations.

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FIGURE 1 SPECIMEN GEOMETRY AND DETAILS OF WELDED JOINT

FIGURE 2 FATIGUE STRENGTH DATA OF TYPE 316L STAINLESS STEEL BUTT WELDED JOINTS SUBJECTED TO ROTATIONAL BENDING LOAD.

FIGURE 3 FATIGUE STRENGTH DATA OF TYPE316L STAINLESS STEEL BUTT WELDED JOINTS SUBJECTED TO AXIAL LOAD.

FIGURE 4 FATIGUE STRENGTH DATA OF STS42 CARBON STEEL BUTT WELDED JOINTS SUBJECTED TO ROTATIONAL BENDING LOAD.

FIGURE 5 FATIGUE STRENGTH REDUCTION FACTOR OF TYPE316L STAINLESS STEEL BUTT WELDED JOINTS.

FIGURE 6 FATIGUE STRENGTH REDUCTION FACTOR OF STS42 CARBON STEEL BUTT WELDED JOINTS.