Numerical Analysis of Hot Cracking in Welded Pipe Structure

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1. Introduction

Inappropriate welding materials and conditions may lead to the problem of weld defects that strongly affect the performance of the welded joints. Therefore, it is essential to draw up effective guidelines to prevent and control the weld defects. Hot cracking and solidification cracking are one of serious weld defects and have been investigated. The research, which generally has been conducted from a metallurgical perspective, involves experimental investigation of the crack susceptibility of various alloys with a particular focus on the influence of inclusions and other metallurgical factors and the influence of the weld penetration geometry on the formation of cracking. Experimental investigations are inherently time consuming and laborious. However, it may be possible to replace experiment by computational techniques for the development of guidelines for materials development and thus to substantially reduce the experimental costs for the determination of welding conditions.

In the present study, we investigated the utilization of an FEM thermal elastic plastic analysis based on plastic strain increment that occurs in the solidification brittleness temperature range (BTR) during cooling to predict the location of solidification crack formation in pipe, and the utilization of a hot cracking analysis based on temperature dependent interface element that we developed for crack initiation and propagation prediction to investigate solidification cracking. Furthermore, the validity of these computational methods for cracking prediction is verified.

2. Restraint hot cracking test of pipe welding

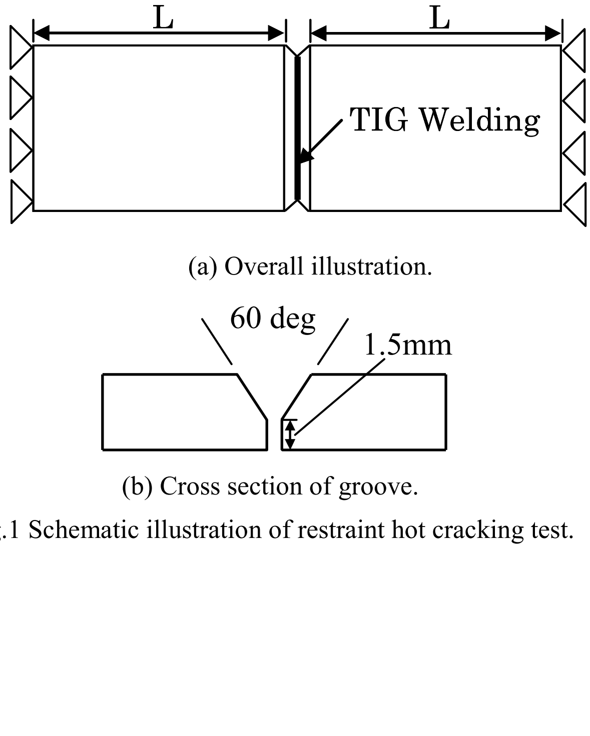
2.1 Test procedure

The hot cracking test apparatus constructed for these experiments is schematically shown in Fig. 1. As illustrated in the figure, pipes were restrained by inserting an SUS304 mandrel into the pipes and fillet-welding it at both ends of pipes. Each pipe was 55 mm in outer diameter with a root face thickness of 1.5 mm. A V-groove with an angle of 30° on each side was obtained by machining the butt end of each pipe. Welding was performed by TIG with 100 A in current, 12 V in voltage, and 100 mm/min in welding speed. The color check was used to investigate cracking in the bead surface.

2.2 Influence of pipe length on solidification cracking

The restraint hot cracking test was performed with pipes of 7 mm in thickness with six different lengths (L in Fig. 1) of 25, 50, 100, 300, 385, and 590 mm. For the pipes of 25 mm length, as clearly shown in the photographs in Fig. 2, the color check test revealed cracking in the regions indicated by the horizontal arrows. Figure 2(a) shows the region centered on 0° where is the weld starting and ending point. Figures 2(b) to (d) show the regions centering on 90°, 180° and 270°, respectively. These photographs clearly show the formation of cracking in various regions throughout the circumferential weld of the pipes 25 mm in length, and in particular, as shown in Fig. 2(a), the formation of nearly continuous cracking throughout the regions on both sides of the weld starting and ending point. In contrast, for the pipes of 50 mm in length, as shown in Fig. 3, cracking determined by the color check test occurred only in the region centering on the weld starting-ending position.

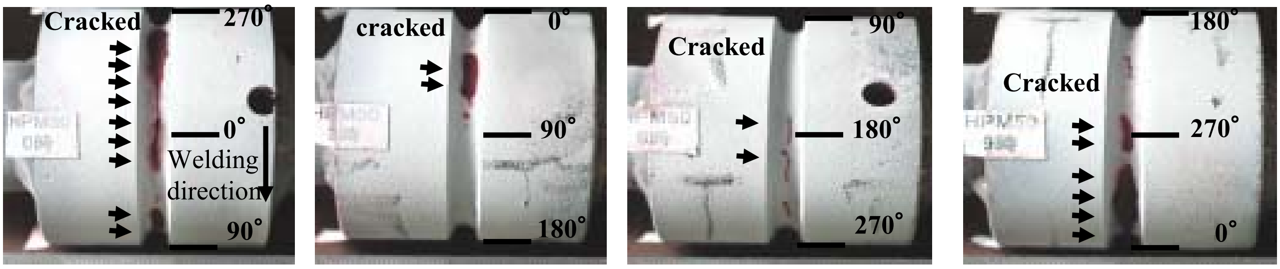
The experimental results are summarized in Fig. 4 in terms of the position and length of the observed cracking regions. The horizontal axis shows the angular position on



(a) Overall illustration.

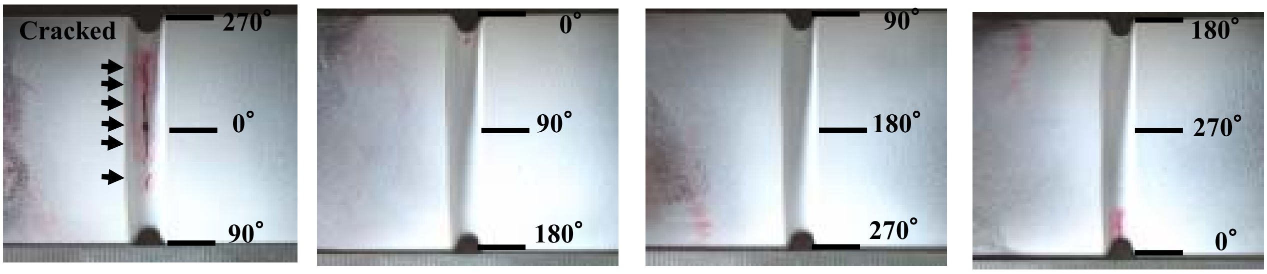
(b) Cross section of groove.

Fig.1 Schematic illustration of restraint hot cracking test.



(a) 0° (b) 90° (c) 180° (d) 270°

Fig.2 Photo of restraint hot cracking test (pipe length: 25mm).



(a) 0° (b) 90° (c) 180° (d) 270°

Fig.3 Photo of restraint hot cracking test (pipe length: 50mm).

the circumferential weld, and the vertical axis shows the pipe length. The figure clearly shows the strong effect of pipe length on crack formation: as pipe lengths become shorter, solidification cracking tends to increase. The shaded bands in the figure also show the cracking positions and lengths predicted by the hot cracking analysis using the temperature dependent interface elements. The predicted positions and lengths are in close agreement with the experimental results, thus indicating that the proposed analytical method was able to predict cracking with good accuracy.

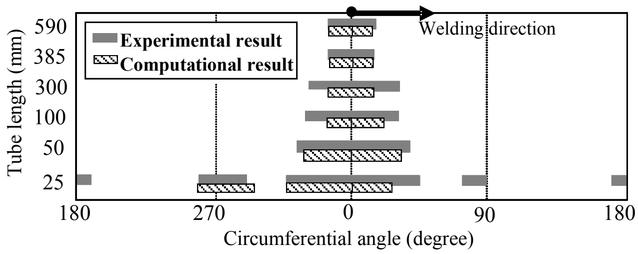


Fig.4 Comparison of experimental results and analytical results on formation of hot cracking.

3. Conclusions

In this study, we performed an FEM thermal elastic plastic analysis using a plastic strain increment in the BTR and a hot cracking analysis using temperature dependent interface element to predict the formation of solidification cracking. Through the comparison of the analytical results with experimental results, the following conclusions are obtained.

1) The results of the FEM thermal elastic plastic analysis were in close agreement with the experimental results, thus showing that it is possible to predict the formation of solidification cracking by using the plastic strain increment in BTR as the index.
2) The results of the hot cracking analysis were in close agreement with the experimental results, thus showing that it is possible to perform a quantitative analysis of solidification crack initiation and propagation by hot cracking analysis using temperature dependent interface element.
3) In the welding of end-restrained pipes, the pipe length strongly affects the solidification cracking and when the pipe length is shorter, solidification cracking tends to be longer.

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