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Effect of the Contact Pressure on the Friction Loss Coefficient in a Micro Gap

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1. Introduction

As one way to improve the reliability of a steam generator for a sodium-cooled fast reactor, a double-wall tube steam generator is being developed. The current development of the DWTSG focuses on the improvement of heat transfer capability for a double-wall tube and the development of a proper leak detection method for the double-wall tube during the operation of a reactor [1].

In the conventional double wall tubes(DWT), the inner tube and the outer tube are made of the same material. When the temperature difference between the inner tube and the outer tube increases, the heat transfer efficiency decreases. To improve the heat transfer capability of a double wall tube, the inner tube is made of a material with a thermal expansion coefficient which is about 10 to 15% greater than that of the outer tube as shown in Fig. 1 [2]. For the on-line and real-time detection of whether the heat transfer tube is damaged or not, a detection method was developed by combining the heat transfer tube gaps and the detection holes meeting with a one-to-one correspondence in the lower tubesheet.

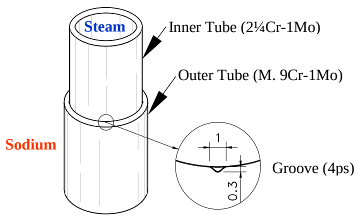

Fig. 1 Double wall tube with the different materials

In the pre-stressed DWT, there is a very small space due to the surface roughness of the inner wall and outer wall. Thus, if the outer wall is broken, the helium gas (2MPa) in the very narrow space is ejected into the sodium (0.1MPa), and if the inner wall is broken, the superheated gas (16.5MPa) is ejected into the space filled with helium gas. If the four grooves with 0.2-04mm depths are dug in the inner surface of the outer wall in order for the helium gas to flow easily, we can detect the leakage by checking the change of gas volume in the on-line groove.

2. Experiment

A preliminary experimental study has been performed to evaluate the validity of this method and to predict the delay time necessary for detecting the fracture. An experimental apparatus has been set up to measure the amount of leakage through the gap by using the initial pressure for the drawing pressure, the contact pressure for the residual stress and the surface roughness as experimental parameters.

The experiments have been performed to measure the amount of leakage of helium gas between two surfaces by pressing the specimen with the hydraulic press for the drawing pressure and the residual stress. The experimental apparatus consists of a helium gas supplying system, a press system and measuring systems for the flow rate and pressure drop.

The range of the experimental parameters for a surface roughness is 0.99-1.284 micrometer. The initial pressure varied for seven cases in a range 50.5-606MPa, and the contact pressure varied for six cases in the range of 5.05-24MPa. The leakage in the gap was measured five times by controlling the pressure of helium gas. The material of the specimen is Modified 9Cr-1Mo steel.

3. Result and Discussion

In this study, only the effect of a contact pressure, which is the residual stress in DWT, is described. A friction coefficient (f) for the pressure loss can be expressed in terms of the Reynolds number (Re) using the following formula;

$$f = \frac{A}{\mathrm{Re}^C} \tag{1}$$

where A and C are positive constants. The experimental data shows that the constant A was strongly dependent on the surface roughness(ε), the initial pressure(P_I) and the contact pressure(P_C). Therefore, the constant A can be expressed as $A=B\cdot F(\varepsilon, P_I, P_C)$, where B is a constant and F is a function of the experimental parameters. The range of the constant C is 1.25-1.45, and the average value is about 4/3 for a micro gap which was measured in the experiment, but the value is a little higher when ε is lower [3].

When the helium gas, which leaks through the gap δ as shown in Fig.2, is assumed as an ideal gas, , the following formula is derived in terms of the mass flow rate m.

$$\frac{\delta}{B^{1/3}}=[\frac{P_o}{4\rho_o(P_o^2-P_\infty^2)}(\frac{2\pi\mu}{m})^C\frac{m^2}{\pi^2}\frac{r_2^{C-1}-r_1^{C-1}}{C-1}]^{1/3} \quad (2)$$

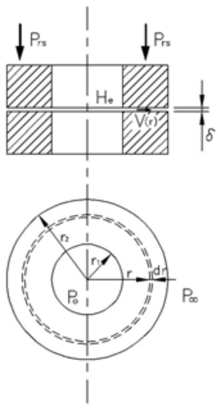

Fig. 2 Geometrical model for the test section

Figure 3 shows a normalized gap ($\delta/B^{1/3}$) in terms of the initial pressure and the contact pressure for the two cases of the surface roughness. The experimental data shows that the normalized gap decreases with the increases of the two pressures. When the initial pressure is higher than the yield stress of the material in the case of low contact pressure, the normalized gap increases with the initial pressure.

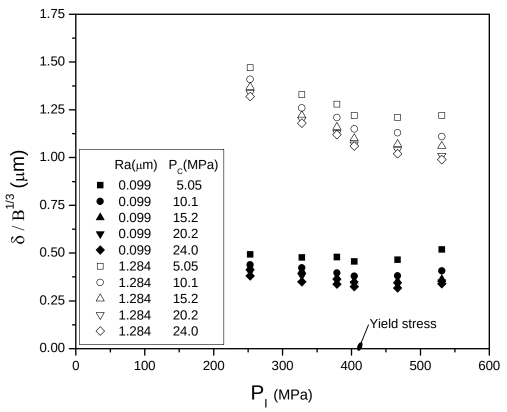

Fig. 3 Hydraulic gap according to the initial pressure

When the surface is assumed as a circular cone shape with roughness (ε) and mean width (S), the gap decreases with the increase of the contact pressure by the Hooke's law as follows:

$$\delta \propto e^{-\alpha(P_C/E)^{1/4}} \quad (3)$$

where E is the modulus of elasticity. In the experiment, the value of the constant α is 5.75(1+5.29S/ε). Figure 4 shows the effect of the contact pressure on the normalized gap.

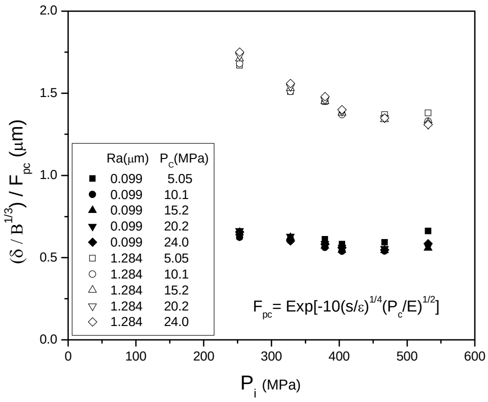

Fig. 4 Effect of the contact pressure on the gap

4. Conclusion

An experimental study has been carried out to evaluate the validity of an on-line leak detection method for a double wall tube and to predict the delay time necessary for fracture detection. The effect of the contact pressure on the gap size is also investigated.

Acknowledgement

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