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Stress Fields for a Coated Surface of an SO_3 Decomposing Heat Exchanger in a Nuclear Hydrogen Production System

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1. Introduction

Nuclear hydrogen production system is being developed based on the very high temperature gas cooled reactor technology and IS cycle technology[1]. There are three important loops, the 1st loop transfers the heat generated from the core to the intermediate heat exchanger, the 2nd loop is an intermediate loop which connects the 1st loop and the 3rd loop of the IS process. The decomposer is a key component which transfers the heat of the 2nd loop to the 3rd loop. SO_3 decomposer operates at high temperature and pressure difference in a corrosive environment[2]. In order to overcome these technical problems, a surface modification technology is implemented to the design of SO_3 decomposer[3]. The surface of the heat exchanger is coated with corrosion resistant material. In addition to this, ion beam mixing technology has been developed to reduce a possible delamination between the coated layer and base material by releasing the stress gradient. As the operating temperature increases, the difference of the thermal expansion coefficient between the coated material and base material causes a high stress value and finally may yield delaminations and/or transverse cracks. In this paper, an explicit expression is presented to estimate the stress fields of a coated layer based on a shear lag concept for an evaluation of the integrity of a coated layer.

2. Design and Modelling

An hybrid design concept is presented in Fig. 1 to meet the design requirements of the SO_3 decomposer[4]. The hot He gas channel is a compact semicircular shape similar to a printed circuit heat exchanger in order to withstand the high pressure difference between loops. The sulphuric acid gas channel is a plate fin type heat exchanger which has a large enough space to install and substitute the catalyst of sulphuric acid gas decomposition. The flow path of He side is not coated but the flow path of SO_3 side is coated with corrosion resistant material. Shear lag analysis which has been developed to analyze bonding of different material has been applied for the present calculation modeling[5]. Stress fields for this coated side is modeled as three different layers which are coated layer, mixed layer and base material. The thickness of the coated layer is thin enough to consider that it has a negligible influence on the global structural behavior of the heat exchanger.

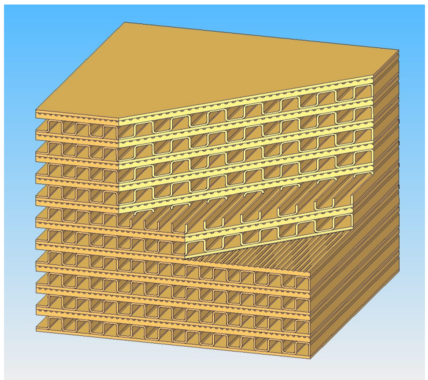

Fig. 1 Effective heat transfer area of hybrid design concept.

3. Stress Calculation

The displacement fields can be assumed as follows when the plate is subject to a constant strain.

$$u_1 = \varepsilon_o x + U_1(x) \quad (1\text{-a})$$

$$u_2 = \varepsilon_o x + U_2(x) \quad (1\text{-b})$$

where U(x) is the displacement perturbation caused by the presence of transverse crack. The transverse shear stress component, which is expressed as displacement difference between coated layer and base material, is dominant in the mixing zone. Loading expressed as strain can be easily obtained from total strain field.

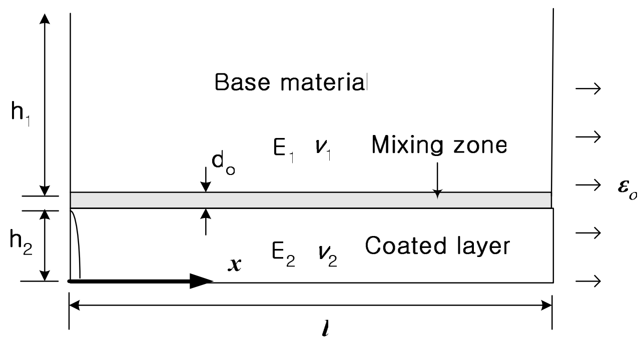

Fig. 2 Explanations for the notations of model.

$$\tau_{xz} = \frac{G}{d_o}(u_2 - u_1) \quad (2)$$

Equilibrium equations are expressed as follows :

$$Q_1 \frac{d^2u_1}{dx^2} + \frac{G}{h_1 d_o}(u_2 - u_1) = 0 \qquad (3\text{-a})$$

$$Q_2 \frac{d^2u_2}{dx^2} - \frac{G}{h_2 d_o}(u_2 - u_1) = 0 \qquad (3\text{-b})$$

where

$$Q_1 = \frac{E_1}{1-\nu_1^2}$$

$$Q_2 = \frac{E_2}{1-\nu_2^2}$$

Displacement field is obtained by solving the differential equations with the stress free boundary conditions at the crack surface. Stain fields can be derived directly from the displacement fields by differentiations. Finally, the stress fields can be expressed as follows :

$$\sigma_x^{(1)} = \sigma_{xo}^{(1)} + \frac{h_1}{h_2}\sigma_{xo}^{(2)}\left(c_1 e^{\alpha_1 x} + c_2 e^{-\alpha_1 x}\right) \qquad (4\text{-a})$$

$$\sigma_x^{(2)} = \sigma_{xo}^{(2)}\left\{1 - \left(c_1 e^{\alpha_1 x} + c_2 e^{-\alpha_1 x}\right)\right\} \qquad (4\text{-b})$$

where

$$\alpha_1{}^2 = \frac{G}{d_o}\left(\frac{1}{h_1 Q_1} + \frac{1}{h_2 Q_2}\right)$$

$$c_1 = \frac{1 - e^{-2\alpha_1 l}}{e^{2\alpha_1 l} - e^{-2\alpha_1 l}}$$

$$c_2 = \frac{e^{2\alpha_1 l} - 1}{e^{2\alpha_1 l} - e^{-2\alpha_1 l}}$$

It means that the coated layer is sound when the transverse crack spacing l becomes infinite. As the temperature elevates, the spacing of the transverse crack is decreased. That is, the number of cracks is increased. The multiplication of the crack can be predicted by the average stress concept. For the SiC coating on the Ni based alloy, the stress distribution at the coated layer is shown in Fig. 3 for various coating thickness.

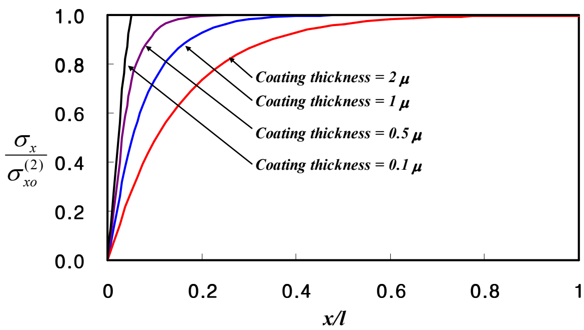

Fig. 3 Stress distribution at the coated surface.

The stress distribution is also influenced by the thickness of the mixing zone thickness as was shown in Fig. 4. However, the Young's modulus difference between the base material and the coating material does not have much influence on the stress distribution.

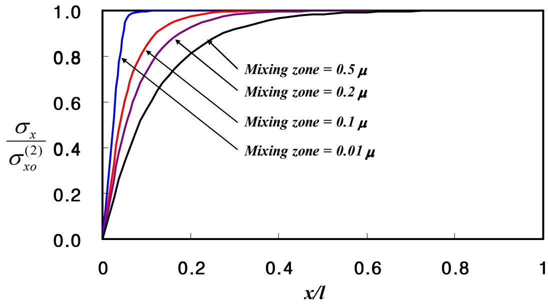

Fig. 4 Effect of mixing zone thickness on the stress distribution of coated layer.

4. Conclusion

Stress fields for a coated layer after a transverse cracking have been calculated based on a shear lag analysis method. It can be used as a simple transverse crack prediction method for a coated surface and an evaluation of the integrity of an ion-beam coating.

ACKNOWLEDGEMENTS

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