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Preliminary FEM Analysis of Diffusion Bonding Process of Alloy 617 Plates

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1. Introduction

One of an emerging technologies in heat exchanger designs is the Printed Circuit Heat Exchanger fabricated by the diffusion bonding of metal plates with micro-channels. Many researchers were focusing on the qualification of bonding interface especially for the minimization of degradation of material properties of the fabricated specimen[1,2]. However, owing to the high temperature which is almost approaching to the material melting point, the bonded plates are generally experiencing the yield stress and the plastic deformation. n this situation, it is also an important issue that the precise prediction of the permanent deformation of the cross-sectional shapes of micro-channels during the diffusion bonding process. In this study, preliminary numerical estimations of the plastic deformation of the alloy 617 plates under the diffusion bonding process using the FEM were presented.

2. Methods and Results

2.1 FEM Analysis Model of Diffusion Bonding Process

Fig. 1 shows the shape of the diffusion bonded specimen and the numerical analysis domain. The specimen is a stack of 50 sheets of alloy 617 plates. For the investigation of material behavior only, there are no micro-channels in the plates. The parameters of diffusion bonding process in this study are as follows:

Material: Alloy 617 (UNS N06617)
Plate dimension: 100mm x 100mm, 1.5t
Total stacks: 50 sheets of alloy 617 plates
Diffusion bonding temperature: 1100, 1150, 1200˚C
Diffusion bonding load: 15 MPa
Diffusion bonding time: 1.5h
Micro-channel inclusion: None

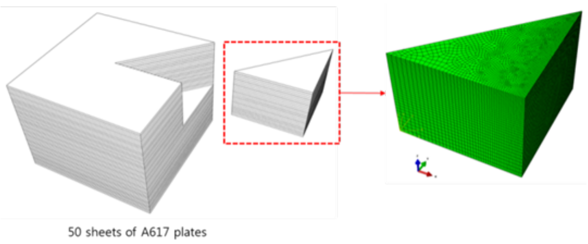
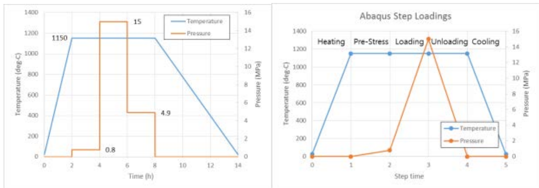


Fig. 1. Diffusion bonding specimen and analysis domain.

Fig. 2 shows the real temperature and loading conditions in the diffusion bonding process, and the FEM analysis steps to simulate whole process which are Heating, Pre-Stress, Diffusion Bonding, Unloading, and Cooling steps. The FEM simulation uses a nonlinear static solver and the step time means not a real clock time but the analysis step increment. The numerical simulation was done using a commercial FEM program, Abaqus[3].



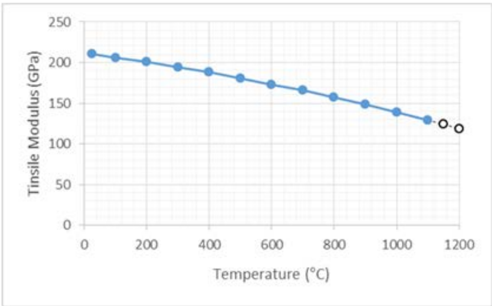
(a) Diffusion bonding (b) FEM steps
Fig. 2. Temperature and loading conditions of real diffusion bonding process and the FEM simulation.

2.2 Material Properties

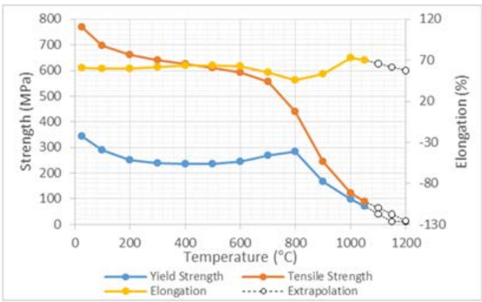
The plastic deformation was assumed to be the main reason of the permanent deformation during the diffusion bonding. The elasto-plastic material properties up to the diffusion bonding temperature are crucial data of the plastic FEM analysis. A vendor-provided material data of alloy 617[4] ware used up to 1000˚C. However, the maximum temperature of the diffusion bonding of this study is 1200˚C and linear or quadratic extrapolations in the temperature range, 1000~1200˚C, ware executed. Fig. 3 shows the tensile modulus, strength, elongation, and coefficients of thermal expansion of the original and the extrapolated data.

2.3 Analysis Results

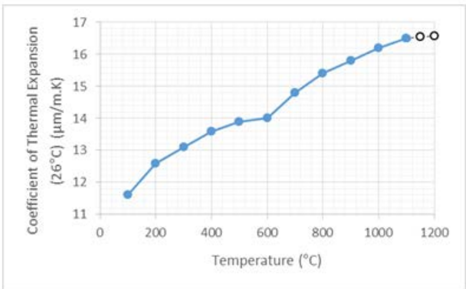
The FE analysis was repeated at 1100, 1150, 1200˚C. There is a contact surface between the loading jig and the top surface of the specimen and the coefficient of friction was assumed to be from 0 to 2.0. Fig. 4 shows the normal stress distribution at the end of the diffusion bonding process at 1150˚C and the results of various coefficient of friction were compared. The figure shows that applied compressive load (15 MPa) exceeds the yield stress (12.5 MPa) and the top edges of the specimen which contacts with the loading jig turns into the most significant plastic region where the frictional force resists the top surface of the specimen to slide. The yielding starts at the coefficient of friction, 0.1 and accelerates until the coefficient of friction reaches 0.2. The plastic region becomes saturated where the coefficient of friction is larger than 0.5. Fig. 5 shows the permanent dimensional change by the diffusion bonding in the height and width of the specimen with the coefficient of friction, 0.2. The figure also shows the effect of the diffusion bonding temperature. At 1100˚C, the yield stress (41.6MPa) is relatively higher than the applied load and the permanent deformation is almost zero. At 1150˚C, the top edges of the specimen have plastic deformation and the specimen shows a considerable permanent dimensional change. This permanent dimensional change accelerates at 1200˚C where the yield stress is 11.5 MPa and the maximum width and height changes were calculated to be 1.37 and -1.53 mm respectively. The thickness changes were also compared with the measurements in a real specimen which were plotted as a gray line in Fig. 5 (b). The FEM results and the measurement results showed a good agreement in trend.



(a) Tensile Modulus



(b) Strength and Elongation



(c) Coefficient of thermal expansion (@26˚C)

Fig. 3. Alloy 617 material properties

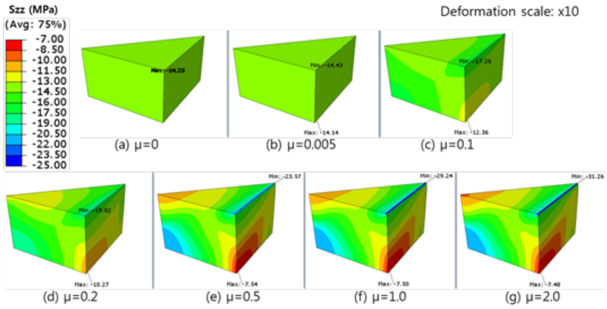
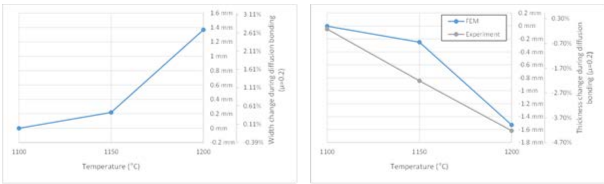


Fig. 4. Normal stress in z-direction at the end of diffusion bonding (1150˚C).



(a) Width change (b) Thickness change

Fig. 5. Permanent dimensional change of diffusion-bonded specimens at various temperature.

1. Conclusion

In this study, a numerical analysis of the diffusion-bonding process of alloy 617 plates was done using the FEM. The stress distribution and the permanent change of the specimen after the diffusion bonding process were calculated at the various temperatures and the coefficient of frictions between the loading jig and the specimen. The results showed that the friction between the loading jig and the specimen has a significant effect on the development of the plastic regions. The effect of the diffusion bonding temperature was also investigated and it was quantitatively showed that the higher temperature accelerates the permanent dimensional changes. The calculated height changes were compared with the measurement values and the two results showed a good agreement in trend.

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