Brazing of C/C composites and Ni-based alloy using interlayer

Toshi-Taka Ikeshoji¹, Tatsuya Tokunaga, Akio Suzumura and Takahisa Yamazaki
Mechanical & Aerospace Engineering, Tokyo Institute of Technology, O-okayama 2-12-1, Meguro-Ku, Tokyo, 152-8552, Japan

ikeshoji.t.aa@m.titech.ac.jp

Abstract. The brazing of C/C composites and Inconel-600 Ni-based heat resistant alloy was conducted using Fe-Ni-Cr-P-Si brazing filler alloy with inserting various thickness of Nb foil as stress relief interlayer. SEM observation of cross section of brazing interface revealed that Nb foil was resolved into the brazing filler layer on C/C composites side. Nb diffused to the surface of C/C composites and acted as the active metal element to enhance the wettability of molten metal on graphite matrix of C/C composites during the brazing process. The variation in shear strength values of the brazed joint with Nb layer thickness suggested that the Nb layer should be remained at least 100 µm.

1. Introduction
C/C composites have the high heat resistance. To utilize the C/C composites’ heat resistance, the brazing techniques of C/C composites and the heat resistant alloys are expected. The brazing of C/C composites to the heat resistant alloys is, however, difficult due to C/C composites’ poor wettability to the ordinary brazing filler alloys, and the relatively large mismatch in the coefficient of thermal expansion (CTE) [1]. In this research, the poor wettability is attempted to be overcome by using the Fe-Cr-Ni-(Si,P) brazing filler, which consists of the carbide forming elements, e.g. Fe and Cr. The residual thermal stress induced by the mismatch in CTE is attempted to be relieved by inserting the Nb foil. The Nb’s CTE value is 7.3×10⁻⁶ K⁻¹, which is intermediate between the CTE value of C/C composites, 1×10⁻⁶ – 8×10⁻⁶ K⁻¹, and that of Inconel-600, 12×10⁻⁶ K⁻¹. By changing the thickness of Nb foil, the brazing test was conducted. And for the obtained joints, the shear strength was measured. Their microstructure at the brazing interface was made clear using the SEM and EPMA elements mapping.

2. Experimental details
The provided materials were a cross-ply laminated C/C composites plate in the dimensions of 10×10×3 mm (Across Inc.) and Inconel-600 (Ni-15.5Cr-8Fe0.25Si-0.2Mn-0.08C-0.001S in mass%) plate in the same dimensions. The interlayer was the Nb foil with the thickness of 100 – 500 µm. The brazing filler was Fe-42Ni-20Cr-(10– 12)(Si,P) alloy (in mass%, TB-2720, Tokyo Braze Co., Ltd.). The Ø100µm Mo wires were inserted as spacers in brazing filler layers (figure 1). The brazing of the specimen was conducted in the vacuum atmosphere. The brazing temperature was 1353 K (1080°C), and the keeping time was 300 s. The cross section of the brazed joints were observed by SEM and the thickness of residual Nb layer was measured. The elements distribution over the cross section of the brazed joint was obtained by EPMA. For the obtained brazed joints, the shear fracture test was
conducted to measure the shear strength. For the shear test specimen, their fillet of the brazed joint was not removed.

3. Results
For all the thickness of Nb foil, the brazed joints were obtained. As shown in figure 2, by the SEM observation, the cracks along the interface of C/C composites and the brazing filler layer were found for the brazed joints with Nb foils with the initial thickness of 100 – 300 µm. On the case of Nb foil with the initial thickness of 500µm, the crack could not be observed. For all the case, the observed Nb layer was thinner than the initial Nb foil thickness. The Nb layer thickness was proportional to the initial Nb foil thickness (figure 3). The regression line was \( y = 1.011 x – 0.075 \) mm, and its intercept with \( x \)-axis was 74 µm. The average of difference between the Nb layer thickness and the initial Nb foil thickness was 72 µm. So, the resolved thickness of Nb foil was approximately 72-75 µm under the brazing conditions of this experiment.

The element distribution over the brazed joint interface on the case of Nb foil thickness of 100 µm are shown in figure 4. The Inconel-600 side of Nb layer was basically the solidified zone of Fe-Ni-Cr alloy. In the C/C composites side, (Fe,Ni)-(Cr,Nb) eutectic phase was observed. The Nb mapping shows it distributes mainly C/C composites side, and especially along the C/C composites surface. Cr also distributed along the C/C composites’ surface. Therefore, Nb and Cr were considered to form the carbides on C/C composites’ surface, and acted as the active elements during the brazing process. The crack was observed near the interface of the solidified brazing filler and C/C composites. In figure 4, the dashed lines shows the outline of the crack. Their shape did not agree because the crack shape changed by depth, perpendicular direction of the picture image.

The shear strength of the obtained brazed joints are plotted with variation in the residual Nb layer thickness in figure 5. The brazed joint with 32µm of the residual Nb layer was too weak to be subjected to the shear fracture test. Other joints’ shear strength values varied from 2 – 16 MPa. The average value of shear strength was high for the residual Nb layer thickness of 127 µm. The average value once decreased for the Nb thickness of 227 µm, and recovered for thickest case.

4. Discussions
The change in the shear strength is considered to be affected by two factors, the thickness of Nb layer and the thickness of brazing filler layer. In this experiments, the solidified brazing filler was considered as Fe-Cr-Ni alloy. The 18-8 austenitic stainless steel, a typical Fe-Cr-Ni alloy, has the CTE value of 16×10^{-6} – 18×10^{-6} K^{-1}, which is larger than Inconel-600’s CTE value, 12×10^{-6} K^{-1}. Adding to it, the thickness of the solidified brazing filler layer was thicker than or comparable with the residual Nb layer.

To examine the effect of thickness of Nb layer and the solidified brazing filler layer, the elastic-plastic FEM analysis was conducted for the same shape with the brazed joint in the experiments (figure 6). The length of sides was 10 mm. The thickness of Nb layer was changed from 0.1 to 5 mm. The solidified brazing filler layer was supposed to have the same physical properties with 18-8 austenitic stainless steel. The thickness of the solidified brazing filler layer was changed from 0 to 0.3 mm. The calculation areas was considered at 1353 K at initial, and cooled immediately to the room temperature, 300 K.

After cooling down of virtual specimen, the stress was induced by the thermal shrinking, i.e. the thermal residual stress. The von Mises’ equivalent stress of the thermal residual stress on the C/C composites surface at the interface with the brazing filler layer was plotted (figure 7). The von Mises’ equivalent stress value decreased with the thickness of Nb layer, and reached to a constant value (figure 7(a)). That value increased with thickness of brazing filler layer (figure 7(b)), though the amount of increase was not so larger compared with decrease with Nb layer thickness.

The difference between the bonding strength of the interface and the von Mises’ equivalent stress of the thermal residual stress can be regarded as the apparent bonding strength of interface. When the value of von Mises’ equivalent stress at the interface is large, the apparent bonding strength of
interface becomes small. According to the FEM results, when Nb layer was thin, the value of von Mises’ equivalent stress is large, and the apparent bonding strength of interface was small. With increase in Nb thickness, the value of von Mises’ equivalent stress decrease, and the apparent bonding strength increased. Therefore, the thicker Nb layer is considered to enhance the shear strength. On the contrary, the thicker brazing filler layer is considered to weaken the brazed joint.

In this FEM analysis, the brazing filler layer was considered as 18-8 austenitic stainless steel, whose CTE value was $18 \times 10^{-6} \text{K}^{-1}$. The previous results suggests that the brazing filler layer on the Inconel-600 side was Fe-Ni-Cr alloy, but on the C/C composites side, it was (Fe,Ni)-(Cr,Nb) eutectic phase. The CTE value of brazing filler layer on the Inconel-600 side could have the similar value of

![Figure 1. Brazing specimen assembly.](image)

![Figure 2. Micro-structure images of the brazed interface of C/C composites and Inconel 600 with various thickness Nb interlayers.](image)

![Figure 3. Thickness of residual Nb layer in the brazed joint interface.](image)
18-8 austenitic stainless steel. That value on the C/C composites’ side is unknown to the authors’ knowledge. According to that CTE values of Fe-Ni alloy is $10 \times 10^{-6} - 20 \times 10^{-6} \text{K}^{-1}$ [3], and that Cr and Nb are $4.9 \times 10^{-6} \text{K}^{-1}$ and $7.3 \times 10^{-6} \text{K}^{-1}$, respectively, CTE value of (Fe,Ni)-(Cr,Nb) eutectic phase might be around their average value, $10.7 \times 10^{-6} \text{K}^{-1}$ in rough approximation. When the CTE value of the brazing filler layer on C/C composites’ side might be lower than the 18-8 austenitic stainless steel’s value, the residual stress would be estimated smaller than the estimated values shown in figure 7. But it will not change the tendency of von Mises’ equivalent stress at the interface between C/C composites and the solidified brazing filler layer to the Nb foil thickness. For the further discussion, the CTE value should be measured actually.

In this experiment, the shear strength should have increased with the Nb layer thickness according to the above FEM results. For 227 µm Nb layer, the residual Nb layer thickness and the solidified

![Figure 4](image1.png)

**Figure 4.** EPMA element mapping for the cross section of C/C composites/Inconel 600 brazed joint with 100 µm Nb foil interlayer.

![Figure 5](image2.png)

**Figure 5.** Shear strength of the brazed joints and the residual Nb layer thickness.
The brazing filler layer thickness became comparable by chance, which lead to the small fluctuation in the shear strength values. But the comparable thickness of brazing filler layer seemed to lower the shear strength in average. The average value for the brazed joints with 427 µm Nb layer must be larger than the value of the brazed joints with 127 µm Nb layer. But the solidified brazing filler was not controlled properly to the constant thickness due to the larger dissolution of Nb into the brazing filler, the experimental results’ value of shear strength was considered scattered in wide range.

5. Conclusions
The brazing of the C/C composites and Inconel-600 inserting Nb foil interlayer using Fe-Cr-Ni-(Si,P) brazing filler was conducted. The Nb interlayer resolved and segregated along the C/C composites surface. It was suggested that Nb could be active element in this brazing process. To obtain the firmly brazed joint, the Nb layer should be remained at least 100 µm.

References
[1] Ikeshoji T-T 2013 Advances in Brazing: Science, technology and application, ed. Sekulic D P Woodhead Publishing Ltd. 394.
[2] Ikeshoji T-T Amanuma T Suzumura A and Yamazaki T 2012 Preprints of National Meeting of Japan Welding Society 90 76 in Japanese.
[3] Matsui M and Chikazumi S 1978, Journal of the Physical Society of Japan 45 458.