# Development of Diffusion Bonding Technology for Heavy Alloys

ヘビーアロイの拡散接合技術の開発

Yasunori ANNOURA

案浦 康徳

Marin KIMURA

木村 愛凜

**Keywords；** heavy alloy, tungsten alloy, diffusion bonding
**キーワード；**ヘビーアロイ，タングステン合金，拡散接合

**Abstract**

For heavy alloys, which are tungsten-based sintered alloys, a diffusion bonding technology has been developed to expand the range of shapes that can be fabricated. In this study, to determine the optimal conditions for diffusion bonding, we investigated the heat treatment and pressing conditions, such as the heat treatment temperature, atmosphere, void space on the bonding surface, and pressure to press the bonding surface.

Investigation of the void space on the bonding surface showed that bonding was possible when the unevenness of the bonding surface was only a few micrometers. We determined the thresholds for the flatness of the diffusion-bonded product based on these results. In diffusion bonding, it is necessary to select the best bonding conditions depending on product shape.

タングステン基焼結合金であるヘビーアロイについて，製作可能な形状の幅を広げるために拡散接合技術を開発した．拡散接合における適正な接合条件を確立するために，熱処理の温度，雰囲気，接合面の空隙，及び，接合面を押さえる加圧力等の条件について検証した。

接合面の空隙について検証した結果, 接合面の凹凸が数 μm 程度であれば接合は可能であることが分かり，この結果を参考に拡散接合品の平面度に関する閾値を決定した．拡散接合では，製品の形状によって最適な接合条件を選定する必要がある．

# 1. Introduction

Heavy alloys are tungsten-based sintered alloys with tungsten as the main component and nickel, copper, iron, and other metals as the binder phase. They are used as weights, shielding materials and mold components due to its high density and easy cutting.

Heavy alloys are manufactured using powder metallurgy techniques in which powder is pressed to form a shape close to that of the product and then sintered. Product shapes are limited by the specifications of the equipment such as press facility and sintering furnace, so it is difficult to manufacture long or large products that exceed the equipment specifications. Previously, products were manufactured by integrating products that were divided into multiple parts by bolting or other means.

Recently, the demands for large and one-piece heavy alloys have increased, so we have developed a diffusion bonding technology for heavy alloys to meet this demand. Diffusion bonding is the method of joining materials by bringing them into close contact and using the diffusion of the atoms that occurs between the bonding surfaces[1]. In this study, we investigated the bonding conditions for diffusion bonding, evaluated the bonding quality and investigated actual examples of commercialized products.

# 2. Experimental

To determine the optimal conditions for diffusion bonding, we investigated the conditions of the heat treatment and pressing method, such as the heat treatment temperature, atmosphere, void space on the bonding surface, and pressure to press the bonding surface. The conditions for diffusion bonding are shown in **Fig. 1**.

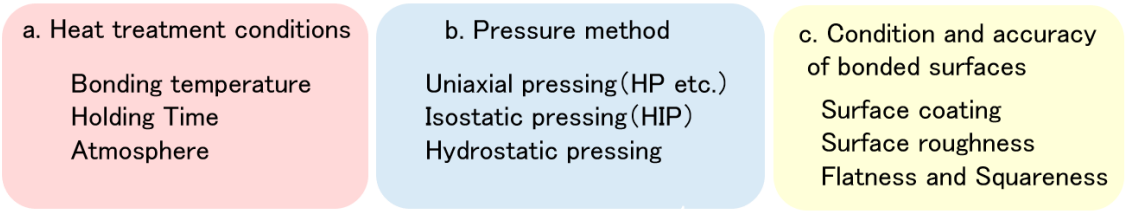



**Fig. 1** Diffusion bonding conditions

As an example, an experiment in which a gap was provided at the bonded surface is shown. This experiment was performed with the objective of determining the flatness threshold of the bonded product. Heavy alloy samples with dimensions of 10 mm × 35 mm × 35 mm were prepared, two for each condition, with a ground surface finish. A schematic diagram of the sample is shown in **Fig. 2**. A flat plate with three grooves with a width of 7 mm and different depths ranging from several to a dozen micrometers was joined to other flat plate with no grooves dug. Thereafter, the finish of the sample after bonding was investigated. Pressure was applied in the uniaxial direction under three conditions: low, medium, and high pressure. The post-bonding condition of the sample was evaluated by ultrasonic testing (C-scope) and cross-sectional microstructural observation.

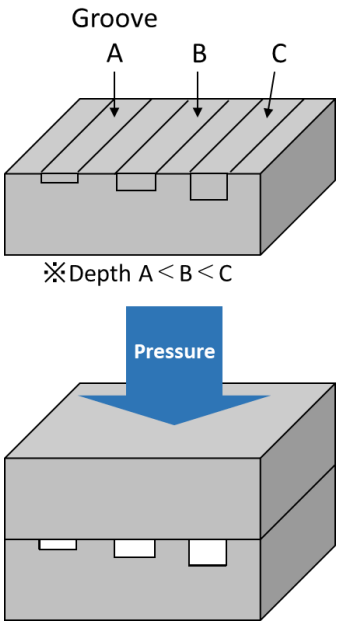



**Fig. 2** Schematic diagram of the experimental sample

## 3. Results and Discussion

The results of the ultrasonic testing (C-scope) are shown in **Fig. 3**. Samples were bonded under three pressure conditions: low, medium, and high pressure. The grooves are A, B, and C in order of decreasing depth (A < B < C).

Groove A was partially bonded. However, grooves B and C, which were deeper than groove A, were not bonded (**Fig. 3**). The depth of the groove on the bonding surface caused significant differences in the bonding conditions. No significant differences in the bonding conditions were observed between the different pressures.

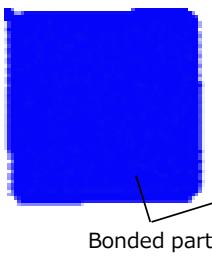
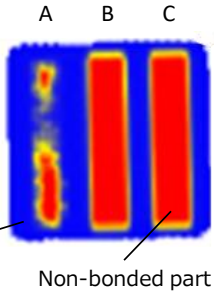
| Sample | Reference piece | Sample① | Sample② | Sample③ |
|---|---|---|---|---|
| Pressure | Low | Low | Medium | High |
| Ultrasonic testing (C-scope) results |  |  |  |  |



**Fig. 3** Ultrasonic testing (C-scope) results

The microstructural observation results of the cross section of the bonded area are shown in **Fig. 4**, and the microstructural observation results of the unbonded area are shown in **Fig. 5**. Although the bonding interface did not have the same microstructure as the base metal owing to the grooves (**Fig. 4**), bonding was possible due to the metal binder seepage. When the grooves were deep, the grooves remained as voids and could not be bonded even after applying pressure (**Fig. 5**).

The results showed that the bonding surfaces can be bonded when the unevenness of the bonding surfaces is only a few micrometers. We determined the thresholds for the flatness of the diffusion-bonded product referring to these results.

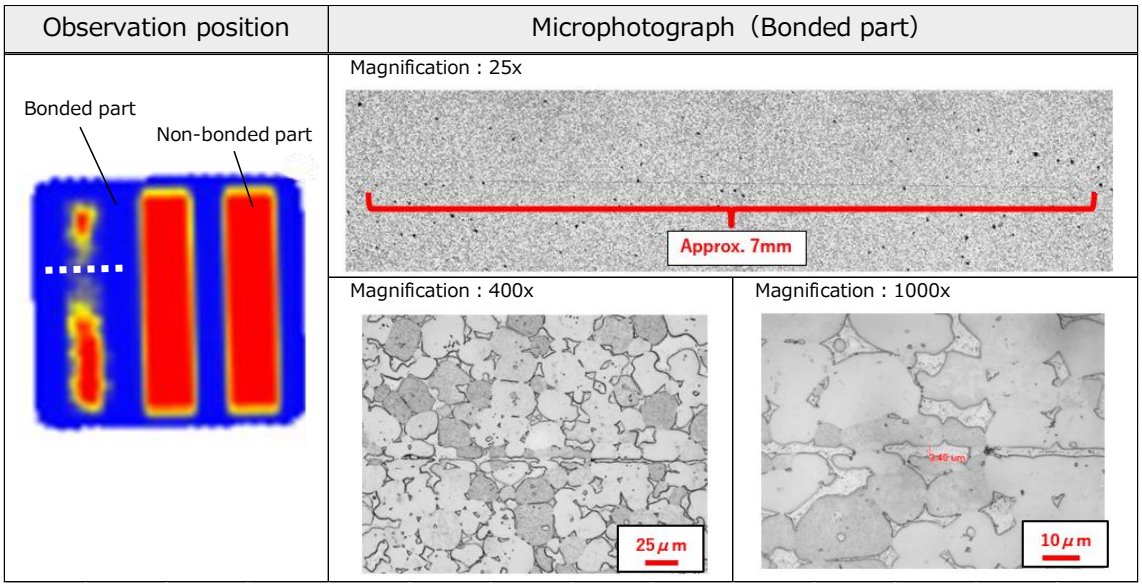



**Fig. 4** Results of microstructural observation of the cross section of the bonded part

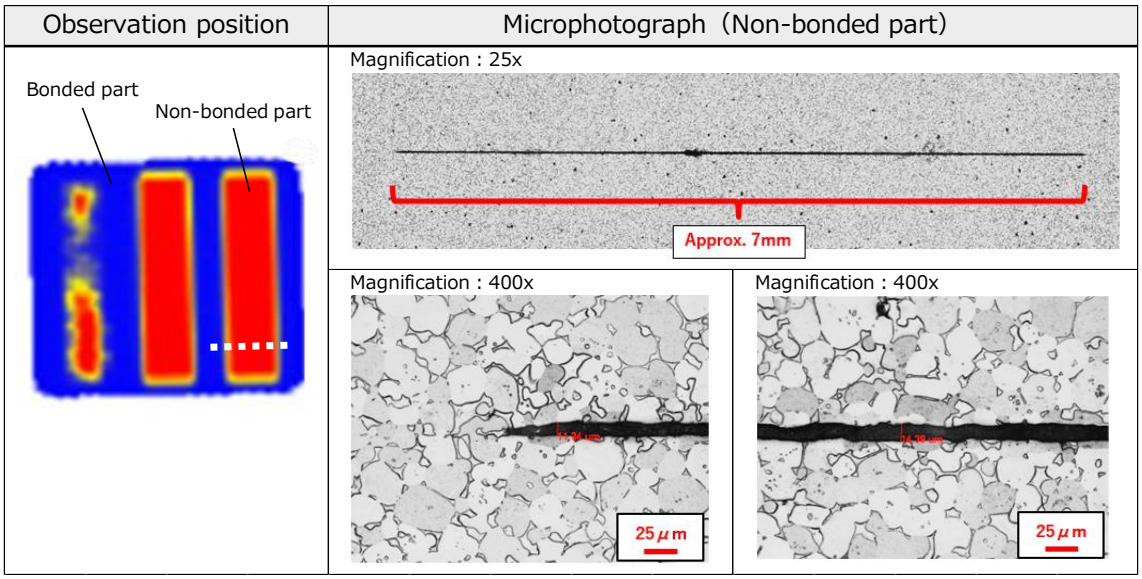



**Fig. 5** Results of microstructural observation of the cross section of the non-bonded part

## 4. Examples of Diffusion-Bonded Products

The development of diffusion bonding technology has expanded the range of component design. An actual example of a long product with a total length of 600 mm made by bonding six 100-mm-long plates is shown in **Fig. 6**. An example of a hollow body product is shown in **Fig. 7**. We have commercialized large balancers and hollow body parts that require a water-cooled (air-cooled) path.

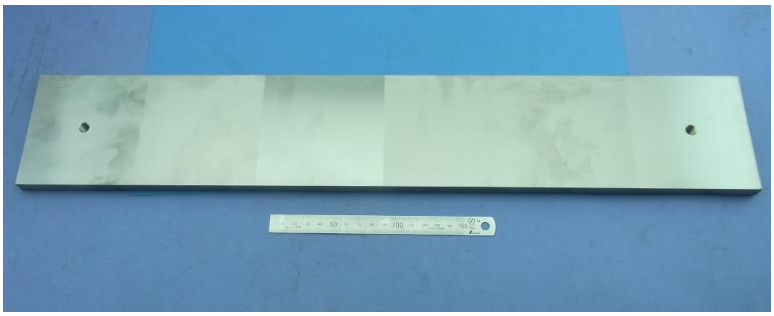
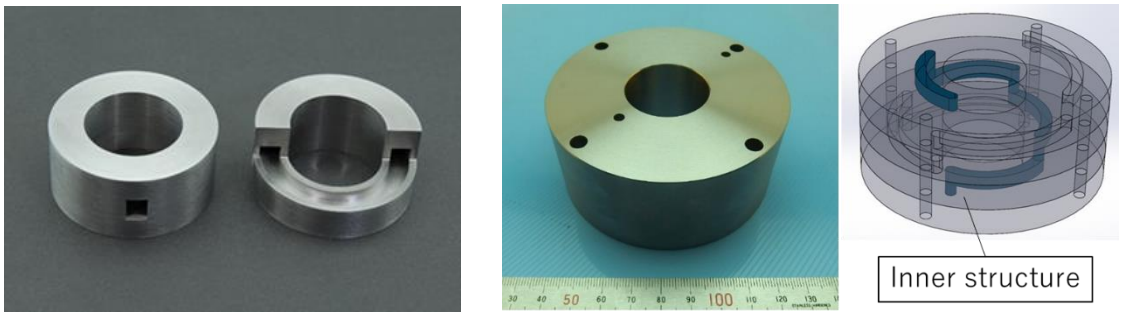


**Fig. 6** Example of a long product




(1) Example 1
(left: exterior right: interior)

(2) Example 2
(left: exterior right: interior)

**Fig. 7** Examples of hollow body products

## 5. Conclusions

To determine the optimal conditions for diffusion bonding, we investigated the conditions for heat treatment and the pressing method, such as the heat treatment temperature, atmosphere, void space on the bonding surface, and pressure to press the bonding surface. In diffusion bonding, it is necessary to consider the best bonding conditions for each product, such as selecting the sintering furnace to be used, the appropriate pressing method for the bonding position and bonding area, and the bonding surface processing method.

In quality evaluation, non-destructive testing (ultrasonic testing) confirmed the presence or absence of voids in the bonding parts. However, it was difficult to evaluate the microstructure of the bonding interface and the detection limit prevented the detection of microscopic defects. In addition, inspection and control of the material before bonding is important because the accuracy of the bonded surface has a significant effect on the quality of the bond.

These investigation and quality control enables the diffusion bonding of heavy alloys, making it possible to process shapes that could not be previously handled. It is expected that diffusion bonding can be applied to various applications with further added value because diffusion bonding is also suitable for joining dissimilar metals.

**References**

[1] O. Ohashi, Q&A Diffusion Bonding, Sanpo Shuppan, 2007.