# Applications of the Hot Isostatic Pressing (HIP) for High Gradient Accelerator Structure

Hiroshi Matsumoto, Mitsuo Akemoto, Hitoshi Hayano, *Atsushi Miura, Takashi Naito, and Seishi Takeda
KEK, National Laboratory for High Energy Physics
Oho 1-1, Tsukuba-shi, Ibaraki-ken 305, Japan

*The Graduate University for Advance Studies
KEK, National Laboratory for High Energy Physics
Oho 1-1, Tsukuba-shi, Ibaraki-ken 305, Japan

*Abstract*

In order to reduce the dark current from disk edges in the traveling wave accelerator structure at field gradient up to 80 MV/m, a new type of disk was proposed which consisted of a part of Titanium around the beam hole area and a part of OFHC outer ward. These two parts are joined by a hot isostatic pressing (HIP) technique. HIP makes diffusion bonding at temperatures ranging from 700 to 850 °C at an isostatic Ar gas pressure of 1,200 kgf/cm$^2$ in a pressure vessel. All samples showed the vacuum leak rate of less than $10^{-9}$ Torr•l/sec and tear strength of about 6.4 kgf/mm$^2$ in the reaction zone between two metals.

## I. INTRODUCTION

The accelerating gradient of the Japan Linear Collider(JLC) is 100 MV/m for the X-band main linac and 50 MV/m for the S-band injector and the pre-accelerator. We have already achieved the acceleration of the electron beam of 0.9 A and pulse width of 0.2 µsec by the traveling wave 0.6 m long structure at the gradient of 85 MV/m with 1µsec RF pulse duration at 50 Hz [1]. At this gradient, however, the dark current is very large from disk edges and breakdown occurs frequently, while at 70 MV/m, beam acceleration is made fairly stably. It seems feasible to operate the accelerating structure at this gradient for the practical use after a reasonable processing period. In this sense, the operation of 50 MV/m at S-band is quite promising.

Experimental studies on the upper limit of the electric field strength in conventional disk loaded structures and single cavities have been reported from several laboratories [2][3]. From these studies, there found many factors to be discussed concerning RF breakdown phenomenon with dark current such as surface finish, micro dusts, electron multiplications and vacuum conditions, etc. However, the fundamental mechanism of the RF breakdown is not yet clear. As is appeared in references [4] and [5], the electron multiplications at disk edges is a main reason to limit the accelerating gradient and the other factors such as surface cleanness, surface finish and vacuum conditions were not serious problems [6]. In order to reduce the dark current and increase the upper limit of RF breakdown, we designed a new disk which was consisted of two metals, OFHC and Titanium(Ti-6Al-4V). As the secondary electron emission coefficients of Titanium is less than unity, the beam hole of a disk is designed to be made of Titanium. We applied diffusion bonding by hot isostatic pressing to join Titanium to OFHC. We made the coaxial columnar blocks with OFHC(outer) and Titanium(inner) by this technique. This paper describes the preliminary results of characteristics of HIP diffusion bonded OFHC-Titanium metals.

## II. EXPERIMENTAL PROCEDURES

### *A. Hot Isostatic Pressing*

Hot isostatic pressing(HIP) is a thermomechanical process for materials that makes use of applied gas pressure in order to achieve high density and diffusion bonding in the treated material. HIP subjects generally a material to pressures as high as 2,000 kgf/cm$^2$ and temperatures up to 2,000 °C in a pressure vessel. The source of the heat is a furnace within the pressure vessel, holding temperatures well below the melting point of the material being processed. This method can be used for a wide range of materials such as metals, ceramics and composites.

### *B. Materials Characteristics*

HIP was applied to diffusion bonding of OFHC cylinders and Titanium bars. The chemical compositions of the samples are listed in Table 1. The composition of the OFHC is very high quality type and the Titanium corresponds to the Japanese Industrial Standards(JIS) type.

Table 1
Chemical composition of OFHC cylinders

| MATERIAL | CHEMICAL COMPOSITION (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PB | ZN | BI | CD | HG | O | P | S | SE | TE |
| OFHC | 5 | <1 | <1 | <1 | <1 | 3 | 2 | 8 | <1 | <1 |
| | CHEMICAL COMPOSITION (%) | | | | | | | | | |
| | H | O | N | Fe | C | Al | V | | | |
| Ti-6Al-4V | *88 | 0.18 | 0.017 | 0.23 | 0.019 | 6.34 | 4.13 | | | |

* ppm (x$10^{-6}$)

### *C. Fabrication Methods*

Samples of OFHC cylinders and Titanium bars were machined from each columnar block. The surface finish(RMS)

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of the inner wall of OFHC is less than 0.5 µm and the one of Titanium bar is less than 0.2 µm. Dimensions of these samples are listed in Table 2.

Table 2
Dimensions of samples

| | OFHC | Ti-6Al-4V |
|---|---|---|
| DIAMETER OUTER | ø 110 ± 0.1mm | ø 40 -0.05/-0.0mm |
| INNER | ø 40 +0.05/+0.0mm | |
| LENGTH | 110 ± 0.1 mm | 110 ± 0.1 mm |
| SURFACE FINISH (RMS) | < 0.5 µm INNER WALL | < 0.2 µm OUTER WALL |

These metals were cleaned by acetone and then Titanium bar was set inside of OFHC cylinder. The sample was placed into a completely leak-tight soft iron capsule. These capsules were pumped down at less than $10^{-3}$ Torr and then sealed-off.

The results at three different temperatures, 700 °C, 750 °C and 800 °C were obtained in a HIP cycle in a pressure vessel. An isostatic pressure was held at 1,200 kgf/cm$^2$ by pure Ar gas for 2 hours. Above parameters for HIP-cycle (temperature, pressure and holding time) are based on metallurgical and economical considerations. A schematic view of the HIP-cycle is shown in Figure 1.

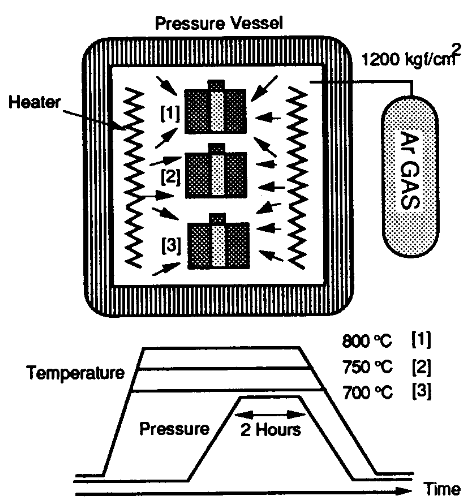


Figure 1.HIP diffusion bonding process.

## III. EXPERIMENTAL RESULTS

### *A. Micro structures*

The quality of HIP was studied with metallographical measurements (optical microscope and scanning electron microscope) and mechanical tests. At three different HIP temperatures(700 °C, 750 °C and 800 °C) with an isostatic pressure of 1,200 kgf/cm$^2$ for 2 hours, all samples became fine micro-strucutre and well homogeneous. In this experiment at these three different temperatures the grain growth of whole OFHC and Titanium was not observed. The micro-structures of a HIP sample and a forged OFHC are shown in Figure 2. The forged OFHC is generally involves large number of micro-pores of a size of a few µm at grain boundary. Figure 2 shows that the micro-pores disappeared in HIP processed OFHC. Moreover, HIP processed OFHC is much more homogeneous than forged OFHC. Titanium is free from porosity even in forged material.

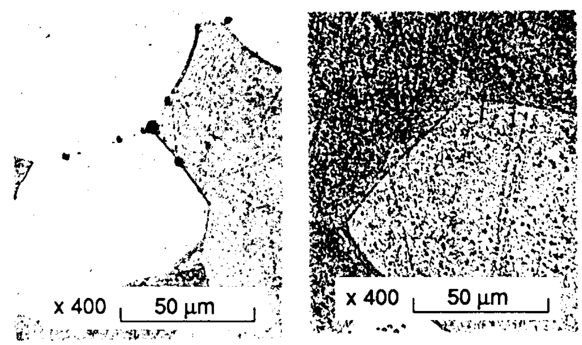


Figure 2. An optical micrograph showing forged OFHC(left) and HIP-OFHC(right) at temperature of 800 °C and the isostatic pressure of 1,200 kgf/cm$^2$ for 2 hours.

### *B. Reaction Zone*

The width of HIP reaction zone in three samples were ranging from 7.3 µm to 20 µm corresponding to applied HIP temperatures. These reaction zone were etched and measured by an scanning electron microscope as shown in Figure 3.

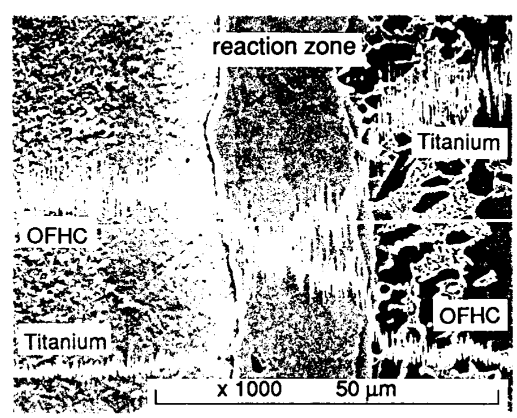


Figure 3. Scanning electron micrograph of HIP processed OFHC-Titanium sample.

Figure 3 shows the reaction zone between two materials which indicates that quality is high and porosities and impurities are not seen. The x-ray analysis of reaction zone in Figure 3 shows the contents of OFHC and Titanium in the reaction zone.

*C. Mechanical Properties*

The quality of HIP was studied with mechanical tests and metallographical measurements. The tear strength was measured using a plates with a thickness of 2 mm which were JIS standard tear test specimens as shown in Figure 4. Five specimens were machined from each sample. The reaction zone is in the middle of the gauge length.

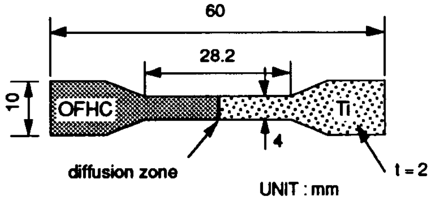


Figure 4. JIS standard tear test specimen. Viewing from top.

We obtained the tear strength of 6.4 $kgf/mm^2$ in average for the three different HIP temperatures. The minimum value of strength was 4.9 $kgf/mm^2$. Figure 5 shows the tear strength of all the specimens, which does not depend on HIP temperature. All of the test specimens were fractured at inside of reaction zone where the concentrations of OFHC and Titanium were equal.

The vacuum leak rate of the reaction zone is well blow $10^{-9}$ Torr•l/sec.

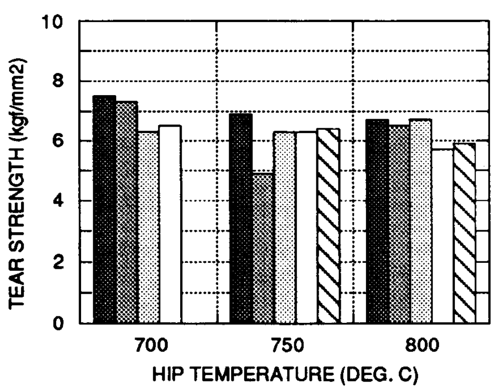


Figure 5. Tear strength by JIS standard test.

## IV. DESIGN OF DISK STRUCTURE

*A. Calculation of Q*

The new disk structure is designed for conventional disk loaded structure which is consisted of HIP bonded OFHC and Titanium metals. The calculated results of Q value by the use of MAFIA coed was 12,000 for the $2\pi/3$ mode. It is about 14 % lower than the normal cavity which is made of only with OFHC. The dimensions and drawing of the cavity are shown in Figure 6.

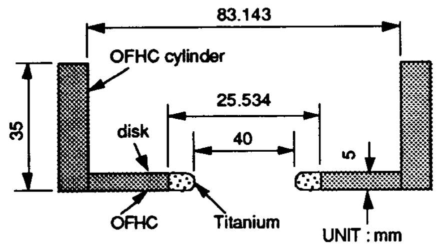


Figure 6. Titanium bonded disk structure.

## V. SUMMARY

HIP diffusion bond of OFHC and Titanium was successfully made at temperatures ranging from 700 °C to 800 °C and the pressure of 1,200 $kgf/cm^2$ for 2 hours. The micro-pores in the OFHC are disappeared with HIP processing. Quality of the reaction zone is high and it is free from porosities and impurities. The minimum tear strength of reaction zone is 4.9 $kgf/mm^2$. The vacuum leak late of reaction zone is less than $10^{-9}$ Torr•l/sec. The calculated Q-value of Titanium bonded disk was 12,000. These results indicate that the Titanium bonded disk can be applied to high gradient accelerator structures.

## VI. ACKNOWLEDGMENTS


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